Charles River City: An Educational Augmented Reality Simulation Pocket PC Game

by

Priscilla Cheung

Submitted to the Department of Electrical Engineering and Computer Science
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Abstract

This thesis has designed and implemented Charles River City, an educational, location-based augmented reality simulation game that uses Pocket PC devices and GPS technology. As mobile devices and processing power become more common and affordable, high school teachers can take advantage of these technological advances to explore new channels for teaching and motivating students. The Charles River City game seeks to engage middle to high school students in learning science in a fun and innovative way. The story and background in the game is loosely based on a previous work called River City, a desktop multi-player virtual simulation game. In Charles River City, students work in teams to investigate the cause of several illnesses in a virtual town. Through interviewing virtual characters, gathering water samples, and analyzing collected data, students learn to think and solve problems as a scientist would. A test run of the game shows that the simulation game is an effective teaching tool that gives students a hands on experience in solving a real world problem that is fun and challenging.

Thesis Supervisor: Eric Klopfer
Title: Assistant Professor, Director, MIT Teacher Education Program

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1.0 Introduction

1.1 Motivation

Educational computer games are often used as a tool to engage students in learning what are sometimes perceived as "non-fun" subjects, such as physics, science, history, and mathematics. They can also be used to complement traditional teaching methods that may be inadequate for passing on certain types of knowledge or learning attitudes. For example, scientific information is often presented in textbooks as absolute facts, without inspiring the student to consider how a conclusion is arrived at or if there are alternatives to a solution. While it is difficult to teach this attitude of scientific inquiry using common instructional strategies, computer games—in particular computer simulation games—can be a valuable tool for addressing this issue.

Computer simulation games can provide a virtual environment in which a student can navigate, investigate, and interact. Information is presented in such a way that students make discoveries on their own, instead of being lectured and told. They learn to solve problems by making careful observations, inferences, and hypotheses, and by applying their knowledge in the subject being taught. The students gain a personal experience in understanding real world processes through virtual data collection and data analysis. Computer simulation games help students engage in scientific experiments or historic events that they otherwise would not have access to while at the same time presenting information in a media that is entertaining and fun.

Traditionally educational computer games are played in a classroom setting or in a computer lab at the school. However, besides being played on a desktop computer, a computer simulation game can also be played outdoors with the help of a handheld computer. With the proliferation of mobile devices and the abundance of computing power available at an increasingly lower cost, teachers can turn such devices as the Pocket PC and the Palm Pilot into powerful educational tools. A specific type of mobile computer simulation game is the augmented reality simulation game using a handheld device and GPS information. In an augmented reality simulation, the player interacts with their surroundings based on their GPS real world location, which provides a context for the simulation. This combination of mobile and GPS technology brings a mobility and interactivity that make augmented reality simulation games a very useful and practical teaching tool.

1.2 Thesis Overview

This thesis project has designed, implemented, and evaluated a location-based Pocket PC Augmented Reality Simulation game called Charles River City. The target audience for the game is middle school to high school aged students. The game makes use of the Pocket PC device and GPS technology to create the simulation of an augmented reality town called "Charles River City" in which an outbreak of several diseases has occurred. The students, as the players, would work in teams to investigate the cause of the diseases and propose a solution to

the problem. The game, as the name indicates, would be played along a segment of the Charles River in Boston.

Before discussing the design and implementation of Charles River City, Chapter 2 of this thesis will describe the previous work of River City, a desktop-based multi-player computer simulation game that inspired Charles River City. It will also describe Environmental Detectives, an earlier augmented reality simulation game used for education. Next, Chapter 3 describes the design and implementation details of the actual Charles River City game, the central application for this thesis. Lastly, Chapter 4 will evaluate the development process, the trial run results, and the game's effectiveness as a teaching tool.

2.0 Background

2.1 MUVEES River City

2.1.1 Overview

The background for Charles River City's game play and design is loosely based upon River City, a Multi-User Virtual Environment Experiential Simulator (MUVEES) game developed at the Harvard Graduate School of Education by Professor Chris Dedes [1]. From this point on in this paper, the original game developed at Harvard will be referred to as "MUVEES River City" to avoid any confusion with this thesis's outdoors simulation game, called Charles River City.

As the title implies, MUVEES River City is a multiplayer game played over a network and a server by students in a classroom setting over several weeks of time. The student acts as an avatar in a 3D world displayed on standard PCs. The 3D graphical depiction of a virtual town and the use of digitized historical museum artifacts provide the simulated virtual environment for the game. As an educational tool, the goal of MUVEES River City is to motivate student interest in learning science and improve educational outcome. In order to solve the problem presented by the game, students have to think as scientists and investigators would, through observing, forming hypotheses, gathering data, making inferences, and forming conclusions based on various evidences.

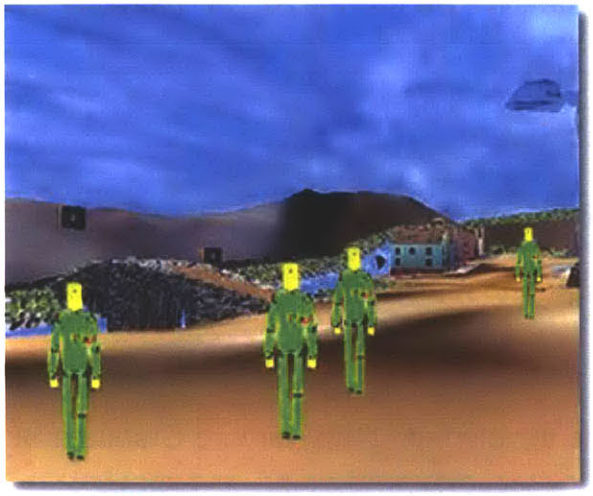

Figure 2.1.1. A snapshot of the MUVEES River City world.

2.1.2 The Setting

The setting of MUVEES River City is a town from the 1880's. The town is divided by a river, and has different kinds of terrain that affect water runoff. There are tenements, houses, industries, a hospital, and a university. Working in teams, students are represented as avatars "sent back in time" to solve the mystery behind the health issues taking place in the town. The dominant diseases in the game are malaria, tuberculosis, and cholera. Malaria is a disease spread by an insect-vector, specifically mosquitoes, while tuberculosis is passed on from person to person, and cholera is a water-borne disease. Consequently, students must understand the ways different diseases are spread and eliminate irrelevant information in order to identify the source of the illnesses in the process of investigation. At the end of the game, the students must come up with a hypothesis of what they think are the causes of the health issues in River City and put together a proposal to solve the problem.

2.1.3 Interaction Within the Virtual Environment

There are several ways through which students can interact with the virtual world in MUVEES River City to find out the cause of the health problems. One way is through facts and clues presented in a straightforward manner to the student. Stationed throughout the MUVEES River City world are information kiosks that provide news about the town and its people, like bulletin postings and maps of the city. At some stations, students can find charts of water sample data that monitor the quality of the river's water. For example, at one kiosk by the river, the player sees the following information upon clicking on the kiosk:

Water Sample Station D – River (On the Bridge)

Ellen Swallow Richards stopped by here to collect water samples for analysis. Here's what she found when she went back to her lab and analyzed the water for each trial.

Cholera Levels in parts per million (ppm)									
Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
0.00	0.00	0.00	0.02	0.06	0.05	0.03	0.01	0.01	0.00

Coliform Bacteria in colonies per ml water									
Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
185	180	180	185	190	180	185	175	180	175

Figure 2.1.2. The posting on a kiosk by the river.

Based on this information, the student can determine that there is pollution in the river water. One of the challenges of River City is to find the source of the pollution in the river water, which poses a health risk for the inhabitants whose water source is the river. Therefore, the information kiosks provide important clues to help the students formulate hypotheses and learn to evaluate the relevance of any given information in the investigation process.

Another source of interaction in the River City game is the virtual characters, also known as Non Player Characters (NPCs). They roam around the River City world and share important information that provides additional insights to the students. As the student's avatar comes within a certain distance of an NPC, he can passively overhear the NPC's conversations and obtain useful clues. Additionally, through "eavesdropping" on the NPCs, the student can experience the type of language that is spoken and observe the culture and the different social classes that existed back in the MUVEES River City historical time period. However, listening to the NPC's conversations is the extent of the interaction between the student and the other virtual characters, thereby limiting the student's activities to that of a passive role. This is a weakness that is addressed in the Charles River City game.

The last type of interaction within the MUVEES River City world is the use of actual historical photographs from the Smithsonian museum's digital archive. These historical photos provide a realistic context for the game. For example, some photographs depict the living conditions of the affluent and the poor in the late nineteenth Century. They serve as clues to point out that various aspects of

different lifestyles can contribute to the spread of the diseases that are plaguing the town, one of which is bacteria caused by water pollution from the new flush toilets adopted by the middle-class households along the river upstream.

Figure 2.1.3. Screenshots from River City that shows the user interface of the game.

2.1.4 Technology and Other Functions

MUVEES River City is built with the Sense8 WorldToolKit, a real-time 3D application development tool. The player navigates the avatar in one window while another window displays information like the town map, the museum exhibits, and the data gathered (See Figure 2.1.3.). There is also an instant messaging function so students can communicate with their own team members. The equipment that is necessary to run River City is simply a set of PCs connected to a network.

2.2 Environmental Detectives

Environmental Detectives is the first Pocket PC augmented reality simulation game used for education and is developed in the Games to Teach Project and the Teacher Education Program at MIT [2]. The game teaches about environmental issues through student collaboration in teams of two or three. It makes use of Pocket PCs and GPS tools to create a simulation of a toxic spill on the MIT campus. Through interviews with virtual environmental experts and well-digging simulations for data collection and analysis, students attempt to discover the location and cause of a water contamination in the grounds of the MIT campus. The game's scenario was designed with the help of two MIT environmental science faculty members. In order to solve the problem posed by the game's scenario, students would need to develop sampling strategies, analyze and interpret data, read and interpret scientific texts to understand the problem, and in the end design a viable remediation plan for the core constituents.

2.3 Other Related Mobile Device Games

2.3.1 M.A.D. Countdown

M.A.D. countdown (Mobile Application Design), is a mobile multi-player hybrid reality game commissioned by Switzerland's University for Design and Art's graduate program of the same name [4]. The game involves plot-driven scenarios about a bomb about to explode on a university campus. The players have to work together to find out where the bomb is and then they have to disarm

it. It is a 2D virtual reality running on Pocket PCs and is location-based using the campus's wireless LAN.

2.3.2 Invisible Ideas

Presented by the Nature and Inquiry artists Group as part of the 2003 Boston Cyberarts Festival, Invisible Ideas is an art project that makes use of GPS technology, handheld computers, and Macromedia Flash [5]. The user, holding the Pocket PC and wearing a headphone, follows a path within a designated area as presented by a map displayed on the handheld screen. There are 147 waypoints along the path where "invisible ideas" are presented through audio and visual narration. As the user walks around, an idea is presented whenever the user walks into one of the waypoints.

The Invisible Ideas project is not technically a game, but it demonstrates how a virtual world can be overlaid onto the real world using a mobile device. In a part of the walk, the participant is led to imagine that Boston Common is like a brain and the user is like a neuron. The participant walking around the myriad of paths within the park is analogous to pulses being fired across the nerves within the brain. Meanwhile, the participant is led to ponder about the human ability to make abstractions and a neuron's connection strengths that hold information. In one instance, the user is told to simulate the activation potential that causes a nerve to fire:

Say the threshold is 10, and that children excite (+ 1) while adults inhibit (- 1). As the participant looks around and counts how many children and adults he sees. Adding and subtracting, he reaches the activation potential when the net gain is 10. At that point, he can simulate a nerve being fired by walking on.

There is not much user-computer interaction in the design of the Invisible Ideas art project. The user takes a very passive role in the experience.

3.0 Charles River City

3.1 Game Design

This thesis has designed and implemented an augmented reality simulation game loosely based on the MUVEES River City game. Charles River City is an educational, augmented reality simulation game played on a Pocket PC and uses GPS technology. It is a game designed as a complementary teaching tool for middle school to high school aged students to be played over a period of about two hours along the Charles River.

3.1.1 Goals

The Charles River City simulation game is designed to provide middle school to high school aged students an innovative and effective learning experience. There are two goals of the Charles River City project. First, it is a study of how an augmented reality simulation game can be used to teach science to middle school and high school students.

A secondary goal of this thesis is to compare Charles River City's effectiveness as an educational tool with MUVEES River City. Both games seek to motivate students in the learning process and engage them in a simulated scientific investigation. They differ in the technology employed and in the degree of immersion and interaction in the simulated worlds. Charles River City would serve as the Augmented Reality model while MUVEES River City would serve as the Virtual Reality model in the comparison study.

3.1.2 An Augmented Reality Simulation Game

In an Augmented Reality Simulation, mobile devices and GPS technology are used in conjunction with the real world environment to create a semi-virtual world in which the players navigate and interact.

For an augmented reality simulation game, the handheld device is best used to present an extra layer of data to supplement information that users receive from their real world context – such as readings from simulated instruments, interviews from virtual occupants of nearby buildings, or real life interactions with other participants in the simulation [3]. It is also lightweight and portable so a participant can easily walk around with the equipment. Also, peer-to-peer IR connections allow communication and exchange of information among students and facilitate a team-oriented learning environment.

One can imagine a continuum where one end represents the real world and the other end represents the virtual world, like the MUVEES River City world. An Augmented Reality Simulation game would fall somewhere in between in the scale. Charles River City would fall near the middle but closer to the reality side of the scale. On this same scale the MUVEES River City project would be on the virtual reality end.

Charles River City is an augmented reality simulation game. In designing Charles River City, we identified three options for how to adapt the MUVEES game to this new platform. In other words, we needed to decide how far away Charles River City would be from MUVEES River City on the virtual reality scale

and to what degree Charles River city would be an augmented reality simulation. The options were:

1) Very similar to MUVEES River City: A straight port of MUVEES River City to the Pocket PC (except without the multi-player feature since there are no server capabilities outdoors). Charles River City would take place in a similar historical time with similar diseases and storyline.
2) An interpretation of the MUVEES River City problem on the MIT campus in a historical time.
3) A modern version of MUVEES River City, highly adapted for modern time and location.

We chose the third option, the one that is most different from the original River City, because it would map the most closely to an augmented reality simulation and take advantage of the actual surroundings.

In the resulting game design, students move around in an actual location by the Charles River in Boston. Each player's position is shown on the Pocket PC's screen with the help of GPS technology. The map that the student sees on the Pocket PC simulates a virtual modern town that makes use of the actual surrounding's geography and buildings.

3.1.3 Story Overview

Players in Charles River City are told that over the past few weeks, the city has been affected by several illnesses that are increasingly becoming a concern to its inhabitants as well as to the government. The students are called

on by the mayor to investigate the cause of the illnesses and to propose a solution to the health problems. Working in teams, each student has a different player role. Three students form one team, and the roles are a Medical Doctor, an Environment Scientist, and a Government Health Official. Upon starting the game, the student would be presented with the following introduction:

> "The Mayor of Cambridge calls you in. It's June 2004, and the Democratic National Convention is coming to Boston in a month (July 26-29th). Some troubling rumors are circulating: some illnesses seem to be circulating. Evidence is suggesting that West Nile Virus, SARS and other ailments are present in Cambridge, and some signs suggest that this year will be a dramatic increase from previous years. The organizers need to decide quickly what they are dealing with and how significant a problem they're potentially facing. Should they simply ignore things and continue business as usual? If not, what steps should be taken by government and health officials? What, if any, information should be made public? Over the next three weeks, your team of researchers (Medical Doctor, Environmental Scientists, and Government Health Expert in Epidemiology) need to gather the facts and make your recommendations to the Mayor."

3.1.4 Storyline

There are three different diseases that pose an actual threat to the inhabitants of Charles River City, as the students would come to learn. While

there may be extraneous information in the game that serves as red herrings, the three main diseases are Severe Acute Respiratory Syndrome (SARS), the West Nile Virus, and the E. Coli bacteria. Like in MUVEES River City, the different diseases are spread through different vectors: human-to-human for SARS, mosquitoes for West Nile Virus, and river water for E. Coli. As a result, there are three main storylines in the game, one for each disease.

3.1.4.1 The SARS Storyline

A traveler returning from visiting Toronto will exhibit symptoms of SARS. Immediately, she is quarantined at home, and eventually gets better on her own. However, because of the highly contagious nature of the disease, it becomes a concern for the organizers of the Democratic National Convention.

3.1.4.2 The West Nile Virus Storyline

There is evidence that the West Nile Virus is present in the city from reports of dead birds and mosquitoes. Moreover, an elderly man becomes ill with one of the West Nile Virus diseases, calling attention to vulnerable populations and the potential risk for an outbreak.

3.1.4.3 The E. coli Storyline

The E. coli storyline involves a number of fraternity members becoming sick with what appears to be E. coli. The source remains mysterious due to the tight-lipped students, until interviews reveal that a late night swim in the Charles

River may be to blame. Information from the Charles River Watershed Association and water samples taken from the Charles River confirm the presence of E. coli. However, as time passes, the level of contamination diminishes. Therefore, this illness will be a relatively low risk for the visiting delegates attending the Democratic National Convention.

3.1.5 What the Students Will Learn

At the conclusion of the game, the team of students should find out that the three diseases in Charles River City are SARS, West Nile Virus, and E. coli. In the process, the students would learn about the cause of each disease, the transmission medium, the resulting symptoms, prevention methods, and treatment methods. In addition to scientific facts, the students would have gained practical experience thinking like a scientist in the investigation process of the game. They would learn about the steps involved in solving a real world problem, from gathering data and interviewing people, to forming hypotheses, verifying or revising those hypotheses, and forming a conclusion.

3.1.5.1 SARS

SARS, which stands for Severe Acute Respiratory Syndrome, is a viral respiratory illness caused by a coronavirus. It was first reported in Asia in February 2003, and has spread globally through international travel, including the United States. According to the U.S. Center for Disease Control, of the 8098 people who had SARS worldwide, 774 died; thus SARS has a mortality rate of

9.6% [6]. However, there have been 192 SARS cases in the United States, but none of them resulted in deaths.

SARS is spread through close person-to-person contact. It is most easily spread through respiratory droplets in which the virus resides. A person may possibly contract the virus by being in the trajectory of someone's cough or sneeze. Another common way of infection is when someone touches a surface or an object contaminated with infectious droplets and then touching his own mouth or nose. Therefore, consistently washing one's hands or covering one's mouth and nose when sneezing or coughing is an important prevention step.

The global SARS outbreak has been contained as of the end of summer 2003. However, there is a possibility that the disease will re-emerge.

3.1.5.2 West Nile Virus

West Nile Virus is a flavivirus that can infect humans, birds, mosquitoes, horses, and some other mammals. The main route of transmission to humans is from mosquito bites. Mosquitoes, in turn, usually become infected by feeding on blood from infected birds.

For humans, infection with the West Nile Virus can lead to some serious diseases, like West Nile encephalitis, West Nile Meningitis, and West Nile Meningoencephalitis – diseases that cause inflammation of the brain, spinal cord, or the membrane surrounding the brain [7]. The WN virus was discovered in the United States since 1999, and has been a seasonal disease in North America since, occurring primarily between late summer and early fall.

3.1.5.3 Escherichia coli

There are many strains of the Escherichia coli (E. coli) bacteria, some of which live in the intestines of human and animals. The particular strain that causes illnesses in humans and animals is the E. coli O157:H7 strain, which produces a powerful toxin [8]. There are several ways that a human can contract an infection: by consuming undercooked or raw food, drinking raw milk, or swimming in sewage-contaminated water. An infection usually results in bloody diarrhea and may even lead to kidney failure. In the Charles River City game, the cause of E. coli infections is due to swimming in the sewage-contaminated water in the Charles River.

3.1.6 Time Frame

The Charles River City simulation game is played out over a period of three weeks in simulated game time. Those three weeks are compressed into a real time of two hours, the expected amount of time the students would have on a typical field trip in which they would participate in the game. The 120 minutes are divided into 20 game days, which makes 6 real minutes equal to one game day. As time passes, the information presented also changes, so the student must weigh the importance of acquiring different data and re-visiting certain virtual characters, and allocate their time accordingly.

3.2 Game Elements

There are four main game elements that make up the Charles River City game. These game elements evolve over time and may not all be visible at the start of the game. Their changing states will be explained more in detail later in Section 3.3.4, which talks about the artificial intelligence in the game. The four game elements are:

1) The player representing the student.
2) The virtual River City inhabitants, or the Non Player Characters (NPCs).
3) The dead birds that are potentially infected with West Nile virus.
4) The water stations where the player can collect water samples.

These four game elements are represented as icons on the map on the Pocket PC's screen. The player moves around in the Charles River City game world and interacts with the other three game elements as they are encountered.

3.2.1 The Player

There are three possible roles the student player can take on, and the three different roles together form a team. The different roles are a medical doctor, an environmental specialist, and a government health official. Each role has different abilities and receives different information throughout the game. Therefore, no one person has access to all the information. In order to completely solve the problems presented by Charles River City, the three roles must work together and share information with each other.

3.2.1.1 The Medical Doctor Role

One of the player roles that the student can take on is that of the medical doctor. The doctor's expertise focuses on illness at the individual patient level. Information is relevant in terms of symptoms and severity. In the game, the player with the medical doctor role has the special ability to diagnose a Non Player Character's health. At the end of each interview with an NPC, the doctor is asked if he would like to take a measurement of the NPC's vital signs. If he chooses yes, he would get a report with results about the NPC's health, including history and current symptoms. The other two player roles, the environmental specialist and the government health official, do not have such ability. With an NPC's health information, the doctor player can hypothesize about the kind of diseases that are spreading among the Charles River City population. The doctor can also keep track of an NPC's health progression and relate it to events that might be linked to an NPC's recovery or deterioration of health.

The Medical Doctor will focus on and receive mainly information about SARS and E. coli. For SARS, the M.D. will have access to individual cases while monitoring suspected cases. For E. Coli, the M.D. will get information on recent individual cases, such as the fraternity brothers, and determine that they are not too serious. Instead, he will determine that the likely cause is swimming in the contaminated Charles River.

3.2.1.2 The Environmental Specialist Role

The second type of player role is the environmental specialist who has a PhD in Environmental Sciences. His expertise is in environmental sampling and analysis. Specifically, the environmental specialist has the special ability to take water samples and bird blood samples.

Information that the Environmental Scientist PhD will focus on relates to West Nile Virus and E. coli. For West Nile Virus, the player can obtain clues and information by collecting samples from both water stations for mosquito larvae and from dead birds. For E. coli, river water samples will reveal that there is E. coli in the water, likely resulting from recent heavy rains causing fertilizer runoff into stream. Water samples over time reveal the bacteria's levels dropping to a safe level, so the problem takes care of itself.

3.2.1.3 The Government Health Official Role

The third type of player role is the government health official, whose background is in epidemiology. The government health expert does not have any special functions that he can perform in the game, but the type of information that he can get from NPCs is unique. Unlike the MD whose expertise is in individual patients or cases, the Government Health Official focuses on populations of people. The Government Health Official also has the ability to obtain detailed local records regarding disease patterns.

In particular, the Government Health Epidemiologist has a special knowledge about SARS. He has access to global and regional health data in aggregate, and understands the disease's incubation period. Thus, he can determine whether a safe period of time has passed and no new cases have emerged. Additionally, the government health official has access to records from Charles River City as well as other local communities that provide valuable perspectives on the potential severity of the illness. Lastly, he also has access to policy options and their historical effectiveness. Therefore, despite not having any special functions to perform, the Government Health Official plays an important role in the game.

3.2.2 Non Player Characters

An important source of information for the student is the Non Player Characters. They may be some type of experts with specific scientific or technical knowledge, or they may just be the random Charles River City inhabitant standing on the street with experiential knowledge or simply opinions. There are eight NPCs in the game. Six NPCs provide scientific data either as patients or providers of useful records. The remaining two NPCs provide "man on the street" and ancillary information. For example, a jogger that the player meets along the Charles might comment "Oh it rained really hard these past two weeks. My garden has been totally flooded. Also, I've noticed that the Charles has been higher on the banks than it normally is." This information would corroborate about sources of E. coli being from fertilizer in water runoff.

3.2.3 Birds

Another type of game element is the bird. There will be dead birds lying around that the student player may encounter. The function of the bird game element is to provide clues about the West Nile Virus story line. Over 100 types of birds have been found dead and identified to be infected with the West Nile Virus in the United States from 1999 to present [9]. Some examples are the American crow, the house sparrow, the Eastern bluebird, and the barn owl. Only the Environmental Specialist player can take blood samples from the dead birds. By confirming that there are dead birds infected with the West Nile Virus, the student can establish that the virus is present in the area.

3.2.4 Water Stations

The last type of game element is the water station. Each water station represents a location where the Environmental Specialist player can collect water samples. It may be at a location by the river, or it may just be a puddle of water on the ground. The river water samples would be mainly tested for E. coli while water collected from puddles would be tested for mosquitoes and West Nile Virus.

3.3 Game Play

The small screen on the Pocket PC is the interface between the player and the augmented reality simulation of Charles River City (See Figure 3.3.1). Students physically move around along a segment of the Charles River in Boston

and its nearby buildings, while they interact with virtual characters living in the imaginary Charles River City.

Figure 3.3.1 A Pocket PC device with GPS receiver.

3.3.1 The Introduction

When the game is launched in the beginning, the player is shown an introductory screen. The introduction screen contains the story and background for the game, broken up into a series of text that the player reads through (See Figure 3.3.2). After the player has finished reading about the situation in Charles River City and his assigned task, a setup screen appears through which the player is asked to input some information (See Figure 3.3.3).

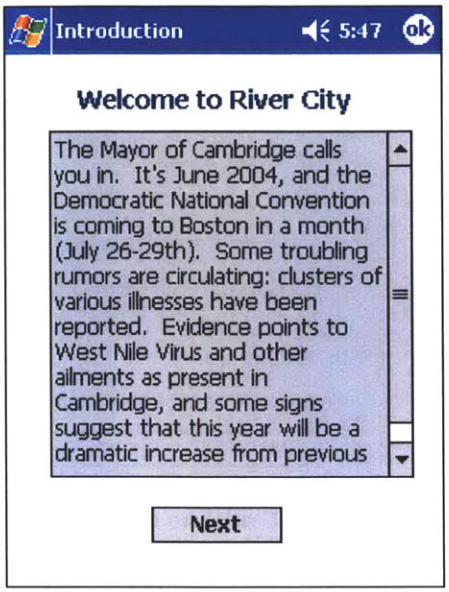

Figure 3.3.2 The Introduction screen of the game.

First on the setup screen, the student needs to select which of the three player roles he would be: Medical Doctor, Environmental Specialist, or Government Health Official. Then, he needs to provide setup information in order for the application to properly configure the machine for using GPS. Specifically, the player will need to enter the port number for reading serial data from the GPS receiver. Which port number is used depends on the Pocket PC device model being used. For example, the Toshiba e740 Pocket PC reads from "COM1" while the Dell Axim X5 uses "COM5". Finally, the player will have the option whether to initialize the game using GPS for navigation or disallowing GPS and using the device's keypad for moving around in the map. Checking the box at the bottom of the setup screen enables the GPS function.

Once all the information is entered, the game begins and the main Graphical User Interface is brought onto the screen.

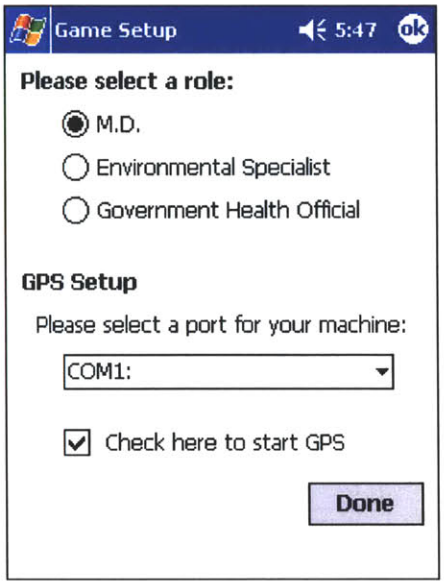

Figure 3.3.3 The setup screen.

3.3.2 The Graphical User Interface

The game's Graphical User Interface (GUI) consists of five main tabs. The default tab is the Main Map screen that contains a real scale map of the game location as well as the game clock that displays time progression in the game. The second tab is the Documents tab, which contains a list of the documents that the player has acquired throughout the game. The third tab is the Data tab, which holds a record of the bird blood samples and water samples that the player has collected. The fourth tab is the People tab, which holds a list of the Non Player Characters that the player has encountered. Clicking on a name in that list brings the fifth and last tab to the front of the screen, which shows detailed information about interviews with the selected NPC and any associated health information for that NPC.

3.3.2.1 The Main Menu

The user interface on the Pocket PC also contains a main menu. Under the "File" option in the menu, a player can choose to "Pause" or "Exit" the game. Selecting the "Pause" function stops the game timer and disables any actions in the game (See Figure 3.3.4). It allows a teacher to have time to gather the class together in the middle of the game to check on progress, hold discussions, ask or answer questions, or give further instructions.

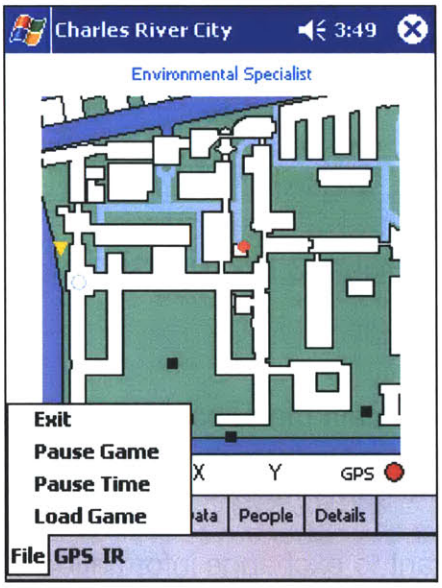

Figure 3.3.4 The File menu items.

The next menu item is the "GPS" submenu. A player can choose to either enable or disable the GPS tracking function for determining location in the map (See Figure 3.3.5). If the GPS function is disabled, the student would use the Pocket PC's arrows keypad to move the player around in the map. If a player is already in GPS mode, he can also choose to enable or disable the manual

keypad input option to allow the arrows buttons to move the player around in addition to using GPS location information.

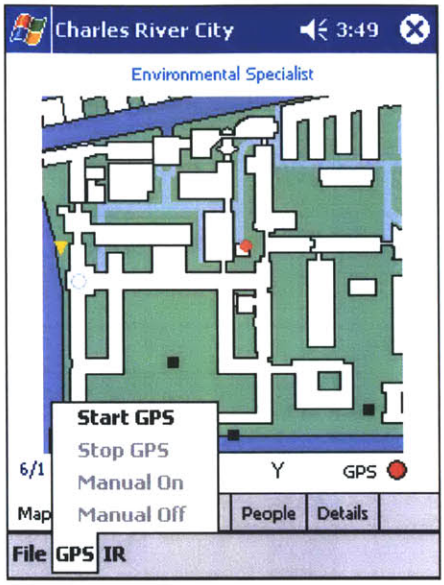

Figure 3.3.5 The GPS menu items.

The last item on the main menu bar is the IR menu. Since the three different player roles in the game receive different information from the NPCs, the players in a team may want to exchange information with each other. They can do so through the Pocket PC's infrared (IR) communication ports. During an IR transmission, the sender and the receiver's IR ports must line up facing each other. Before the sender presses "Send", the receiver needs to click on the "IR" menu, and select "Accept IR" (See Figure 3.3.6) to open the device's IR port for listening to the incoming data. Once the data is received, the recipient device's IR port closes to free up processing power to run the game.

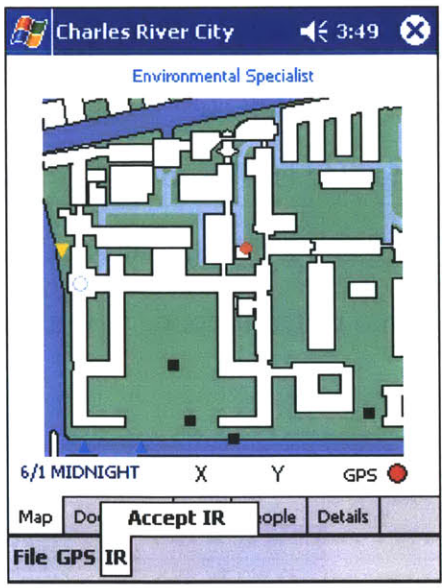

Figure 3.3.6 The IR menu item.

3.3.2.2 The Main Map Screen

Throughout the game, the student can navigate freely throughout the five screen tabs, except when the game is paused. The first and default tab of the game's user interface is the Map screen. This tab shows a 200 by 200 pixels map of the game location (See Figure 3.3.7).

Superimposed onto the map are icons that represent the locations of the different game elements. The player is represented by an orange circle that moves as the player moves. As described briefly earlier, there are two ways that the player can maneuver around the map: through GPS location information or through the arrows keypad on the device. With the GPS function turned on, the game processes the player's physical location from the GPS data and translates it into the corresponding scaled game coordinates. The game performs this calculation once every second, and updates the player's location on the screen if

the position has changed. At the start of the game when the GPS receiver does not yet have a fix on the reading, a light to the right of the map shows the status of the GPS function. The light is labeled "GPS", and is red when GPS is not yet working. Once a fix is acquired, the light turns green, giving the player a visible confirmation that the game would respond to the player's change in physical location.

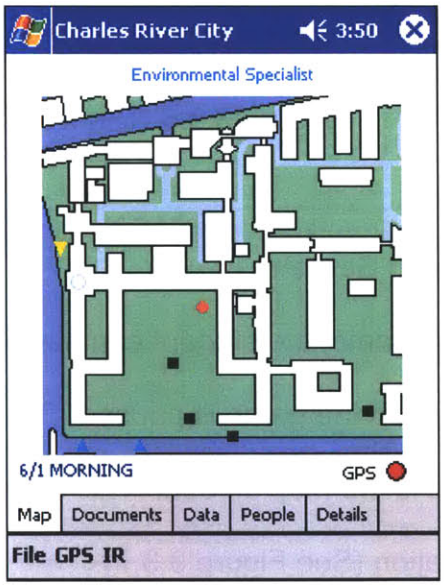

Figure 3.3.7 The default tab showing the map and game time.

If, on the other hand, the player chooses to use the manual mode of navigation, the player icon would move in response to which arrow of the keypad is pressed. The purpose for this manual mode of operation is that it allows ease of testing during trial runs of the game and in the development process. It also provides a backup ability to move the player in case of poor GPS readings or when the player is trying to reach a physically inaccessible location, such as over

the river water, although care should be taken that such actions would not be necessary.

The other game elements displayed on the map are the NPCs, the birds, and the water stations. The NPCs are represented as small black squares, while dead bird locations show up as a yellow upside-down triangle, and blue right-side up triangles represent water stations where the player can gather water sample data.

Besides the map, the game's time is also displayed at the bottom right corner on the front tab. As described earlier, the game spans 20 days or approximately three weeks in an actual period of two hours, each game day being six minutes in actual time. At the start, the date is June 1, midnight. The clock display changes every quarter of the day, or 1.5 minutes in real time. The quarter days are named as midnight, morning, noon, and evening (for times 12 a.m., 6 a.m., 12 p.m., and 6 p.m.). For example, after 9 real minutes into the game, which is equivalent to 9/1.5 = 6 ticks of the game clock, the time would show " 6/2 Morning".

Lastly, the "Map" tab also shows the current player's role, as in Medical Doctor, Environmental Specialist, or Government Health Official. Also, if the player clicks on any of the game icons, the name of the game element clicked would be displayed; for example, the name of the NPC, the name of the bird, or the identification name for the water station.

3.3.2.3 The Documents Tab

The second tab of the user interface is the Documents tab. At each interview with an NPC, the player may receive a document that contains useful information according to the NPC's knowledge and expertise. The documents that the player receives are stored in the virtual folder in the Documents tab (See Figure 3.3.8).

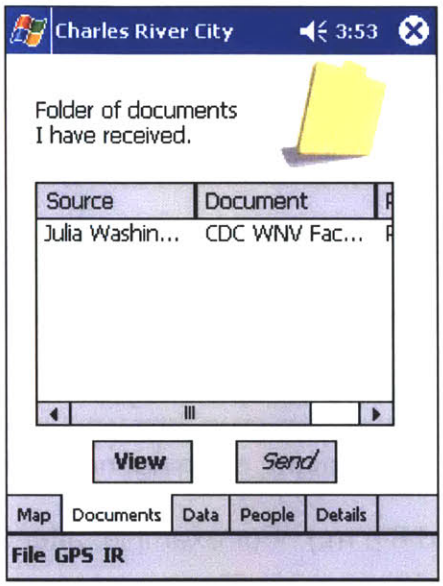

Figure 3.3.8 The Documents tab.

This tab shows a list of the documents that a player has, as well as the name of the NPC person that the player has received it from. At any time in the game, the player can choose to review a document by selecting its entry in the list and clicking on the "View" button. Game documents are stored as html files and are viewed using the Pocket PC software's Internet Explorer web browser. In addition to viewing a document, a player can also send one to another player, by

pressing on the "Send" button. The documents are sent through the Pocket PC's infrared capabilities.

3.3.2.4 The Data Tab

The third tab, or the data tab screen, holds information on bird blood samples and water samples that the player has collected (See Figure 3.3.9). The player can either choose to view the bird blood samples collected or the water samples collected, by clicking on the corresponding button at the bottom. When the type of data sample is selected, the table on the screen displays information about each sample taken with the following attributes: the name of the game element, the type of sample taken, the result of the lab test, and the date the sample is taken.

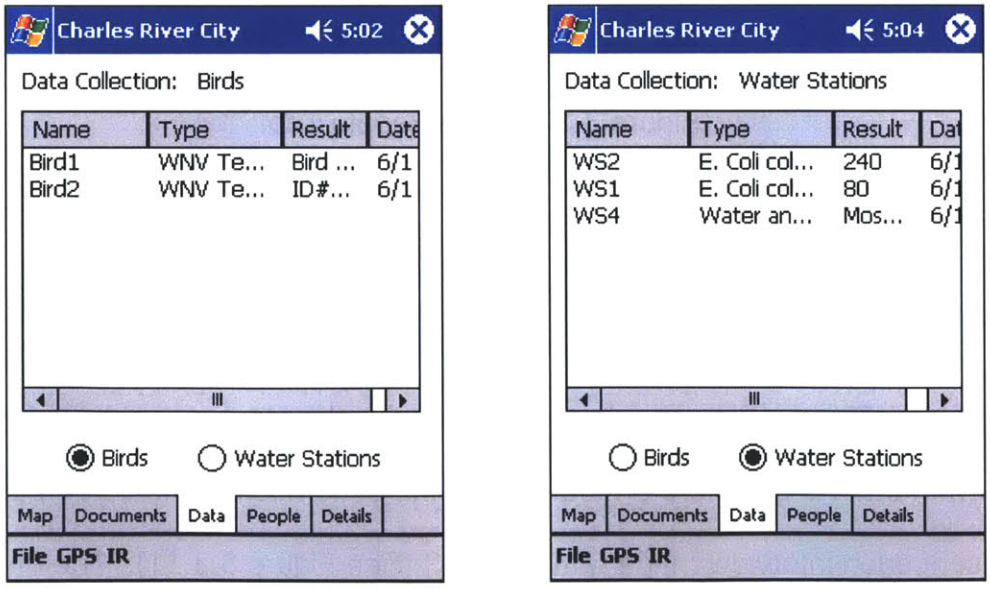

Figure 3.3.9 The two tables in the Data tab.

3.3.2.5 The People Tab

The fourth tab is the People tab. This screen shows a list of the Non Player Characters that the player has encountered and interviewed with (See Figure 3.3.10). By clicking on a name on the list, the player is brought to the Details tab, described next below.

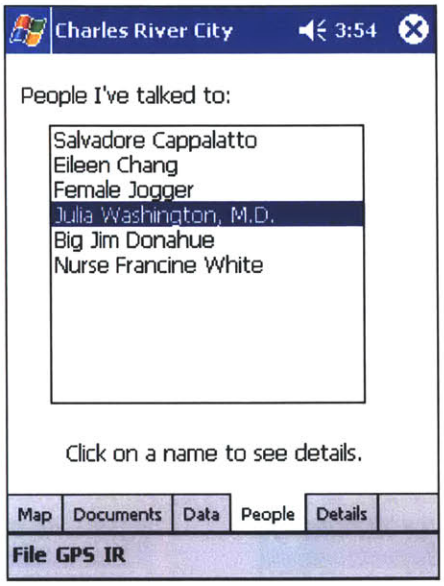

Figure 3.3.10 The People Tab.

3.3.2.6 The Details Tab

The last tab, the Details tab, displays all the interview information associated with an NPC. The default is to display the most recent interview made with that NPC. There are buttons on the bottom left of the screen that represent each interview made with the NPC (See Figure 3.3.11). The buttons are labeled by the date the interview is made, and the number of buttons visible depends on how many interview is made so far. There are a total of three

interviews possible for each NPC for each player role. Once again, a player can send a specific interview to another player, by pressing the "Send" button at the bottom right corner of the screen.

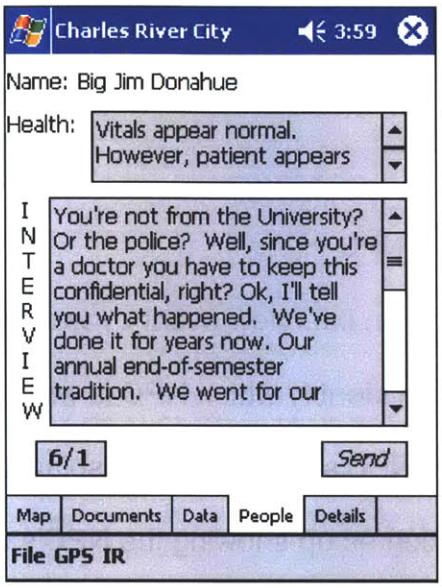

Figure 3.3.11 The Details Tab.

3.3.3 Gathering Information and Collecting Data

The main activities in the Charles River City game are to gather information through interviews with Non Player Characters and through collecting scientific data from dead birds and water samples. The students must allocate their time and divide up their work to reach as many destinations as possible and to gain as much information as possible in order to solve the problem. They will need to share the information that they have acquired as different roles, and put together a complete picture of the situation in Charles River City.

Each game element's icon present on the map screen can be thought of as a hotspot. Whenever a player walks into the hotspot, an event is triggered, depending on the type of game element the hot spot represents. There are three types of events possible, one for each type of game element that the player interacts with: making an interview with an NPC, taking blood samples for a dead bird, or taking water samples from a water station.

3.3.3.1 Interviewing an NPC

Players may trigger an interview event by walking into a NPC hotspot. Once again, the player can identify which NPC is which on the map by clicking on the NPC icon, and the NPC's name will be displayed. When an interview is triggered, a new screen comes up showing the NPC's name, a description about the NPC, a picture of the NPC, and the option to either take an interview or return to the game.

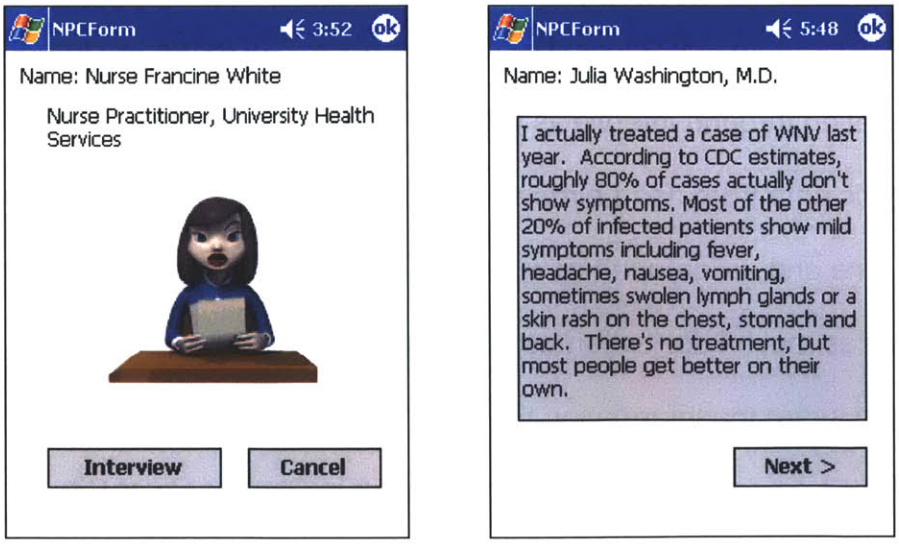

Figure 3.3.12 The interview screens after walking into an NPC hot spot.

If the player chooses to take an interview, the content of the interview is shown in a series of text (See Figure 3.3.12). At the end of each section of text, the player simply presses the "Next" button to move on to the next part of the interview. At the end of the interview, if the NPC is giving the player a document, a "View Document" button shows up and the player has the option to view the document through Internet Explorer.

Lastly, if the player is of the Medical Doctor role, he can either choose to perform a health diagnosis of the NPC or skip the step and return to the game. Otherwise, if the player is either the Environmental Specialist or the Government Health official, he does not have this option and is simply returned to the game. If the Doctor player presses the button to take some health measurements from the NPC, another screen with the results is shown (See Figure 3.3.13).

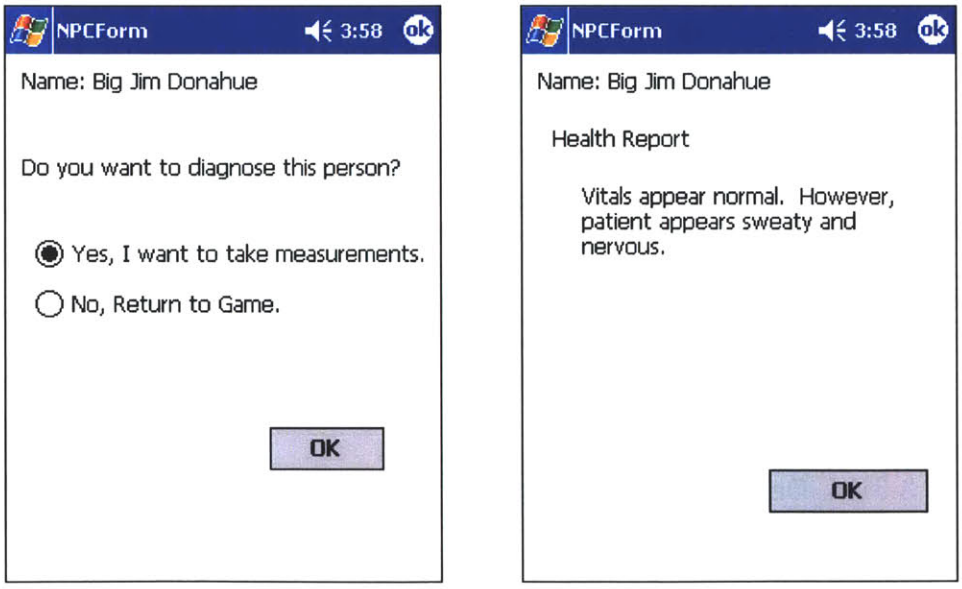

Figure 3.3.13 Diagnosing an NPC by the M.D. role.

After each interview is over, the name of the visited NPC is added to the list in the People tab and the interview content and associated health report is available for reviewing in the Details tab.

3.3.3.2 Taking Bird Blood Samples

When a player walks into a dead bird hotspot, a bird event is triggered. A new screen comes up with information about the bird's identification name, a description about the bird, and a picture of the bird. If the player is either a Medical Doctor or a Government Health Official, he can take no further action and must press the "OK" button to return to the game (See Figure 3.3.14).

Figure 3.3.14 Dead bird hot spot screen for players other than the Ecologist.

If, on the other hand, the player is the Environmental Specialist, he can choose to take blood sample from the bird (See Figure 3.3.15). When he

presses the "Take Sample" button, a report is returned immediately. The report shows what type of data was analyzed, and the results of that analysis. The dead bird analysis report lists an arbitrary identifying number, bird species, city/town where the sample was found, and results of WNV testing (positive or negative). After the Environmental Specialist finishes with the action and returns to the game, the data just collected is added to the table in the Data tab for future reference.

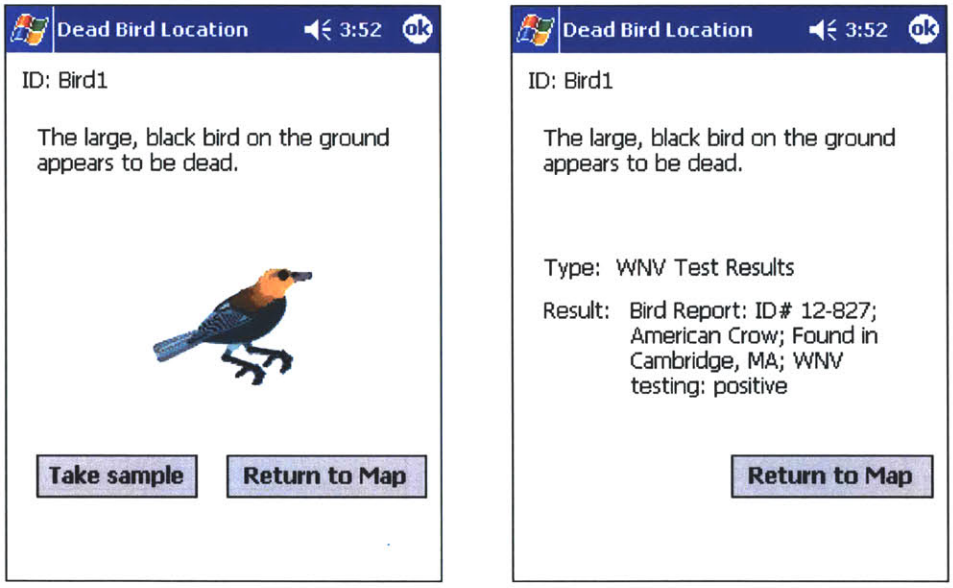

Figure 3.3.15 Taking a bird blood sample by the Environmental Specialist.

3.3.3.3 Taking Water Samples

The water station events are very similar to that of the bird events. When the Environmental Specialist player walks into a water station hotspot, he gets a description of the water station, the name of the water station, and the option to take some water sample (See Figure 3.3.16). The report he receives also

shows what type of analysis was performed on the water sample at that specific water station, and the results of that analysis. That information will be added to the Water Stations table in the Data tab of the GUI after the Environmentalist returns to the game. For the other two player roles, they also get to see the description about the water station, but do not have the ability to collect any data from the water samples.

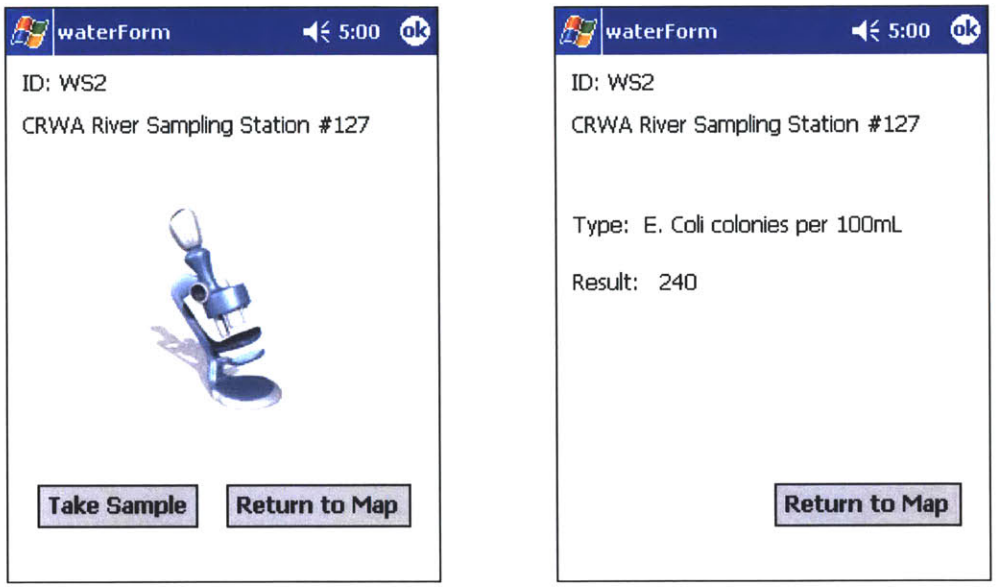

Figure 3.3.16 Taking water samples by the Environmental Specialist.

3.3.3.4 Player-Player Interaction

The Charles River City game is designed to encourage interaction among the players. One type of interaction is the collaboration that the players have to make as different roles working together as a team. Since each role has different abilities and access to different information, each player only has a partial picture of the situation. Therefore, the players need to communicate frequently with

each other, compare any notes or hypotheses, and plan on what steps to take given a limited amount of time.

The second type of player-to-player interaction in the game is the ability to send documents or interviews to each other through infrared. This facilitates the sharing of information among different player roles, and possibly even the collaboration with other teams to divide up the work in order to maximize efficient use of limited time. For example, the Medical Doctor from one team would visit half of the NPCs while the Medical Doctor from another team would interview the other half, and they exchange interviews afterwards by beaming them to each other.

A more important function, perhaps, for sending an interview to someone else is that an interview event may trigger another event, such as causing a previously unknown Non Player Character to become visible on the screen. In order for a player to be aware of the "hidden" NPC, the interview that made the discovery must be sent to the player. These "interview-dependent" events will be discussed more in detail in the section following. In conclusion, each team member will need keep each other updated regarding new game elements appearing and send to others the interview that caused the triggered event, or else one player role may be missing out on important information that could have been obtained from going to the new hotspots. Therefore, player-to-player interaction is a crucial element to successfully solving the game.

3.3.4 Artificial Intelligence

The Charles River City simulation has some very simple artificial intelligence in the game play. The game evolves over time in response to the actions that different players take.

3.3.4.1 Player Differentiation

As described before, one type of intelligence in the game is the existence of three different player roles, each with different abilities and access to distinct information. The Medical Doctor can diagnose an NPC, while the Environmental Specialist can take bird blood and water samples. An NPC responds differently to different player roles during interviews. The information he gives may be different, or he may give a document to one type of player but not to the others.

3.3.4.2 Time-Dependent Events

Another type of intelligence in the game is changes in the game elements as time evolves. In Charles River City, the 2 hours of game play (equivalent to 20 days in the game), is divided up into three time chunks, transparent to the player. Each time chunk is approximately one week long in game time, and represents a different state in the game. Specifically, the state of the NPCs, the birds, and the water stations change in each time period.

First, the information that an NPC gives in an interview can be different in each time period. So, not only does an NPC's interview differ by player roles, it also differs by time periods. With three time periods, three different player roles,

and ten different NPCs, there is a total of 90 different interviews possible in the entire game. Obviously, if an NPC has no new information to give in a later time period, his interview can be the same as the one before. This is why the game keeps a record of up to three interviews in the Details tab for each player role for each NPC.

Besides interviews, bird blood sample and water sample data are also time-sensitive. In particular, river water samples change over time since water current can flush away contamination if its source is not constant. The figure below is an example of how water sample at a water station may change over time. RiverStation2 and RiverStation3 are downstream from a runoff point and therefore show higher levels of contamination.

Results of E. Coli testing in Charles River Station #1-3 *MA State Standard: 126 colonies per 100mL maximum*			
Time	RiverStation1	RiverStation2	RiverStation3
T1 (week1)	80	240	210
T2 (week2)	85	180	170
T3 (week3)	20	30	40

Figure 3.3.17 An example of how water samples change over time.

Since NPCs, birds, and water stations change over time, players will need to strategically revisit each hotspot throughout the game. If the player missed

getting an NPC's interview from one of the time periods, the player would simply not have the information associated with that interview.

3.3.4.3 Interview-Dependent Events

At the start of game, not all NPCs, birds, or water stations are visible to the player. These hotspots only become visible when a player finds out about their existence through talking to an NPC in an interview. These "Interview-dependent events" are the last type of intelligence in the Charles River City game.

Since an NPC's interview differs by player roles, some of the players may not learn about the "hidden" game elements directly from an NPC. In these situations, they can find out by having the interview that triggered the event sent to them through infrared. For example, a Government Health Official player might learn from an interview with an NPC that there is an expert on SARS in the building down the road. As soon as the interview ends, a new black icon representing the SARS expert shows up on the Government Official's screen. The other two players may not learn about this new SARS expert NPC since they might not get the same information when interviewing the first NPC. Therefore, by having the Government Health Official player send his interview to the other two players, they can also find out what was said in that interview, as well as find out about the new SARS expert character. This new NPC will then also appear on the map on their screen. As a result, they can go and talk to the SARS expert, who might provide useful information to any of the player roles.

Lastly, players might use IR to pass clues that a different character will need to act upon. For example, the doctor might find out about the location of a dead bird that the Environmental Specialist will have to collect and analyze.

3.4 Implementation

3.4.1 Technology

As Global Positioning Satellite technology and handheld computers are becoming increasingly common and affordable, their use as educational tools becomes more applicable. Together, GPS and handheld computers enable applications that require mobility and position awareness. The two technologies are especially valuable for augmented reality simulations, which overlay virtual information onto the real world based on one's location.

Currently, there are two Pocket PC models used for the Charles River City game. One is the Dell Axim X5 model running on the Microsoft Pocket PC 2002 Premium operating system, with 400 MHz processors and 64-MB SDRAM. The other is the Toshiba e740 model also running on Microsoft's Pocket PC 2002 Premium operating system, with 400MHz XScale processor and 64-MB SDRAM. Both Pocket PCs have an infrared port this is used for the game's IR functions. A standard Pocket PC screen is 2.25" x 3" big.

The GPS receiver used for the project is the Holux CF GPS Ultra, by Semsons & Co. Inc (http://www.semsons.com/holuxcfgps.html). It uses second generation SiRF II LP chipset with enhanced firmware for better sensitivity and accuracy, and can track up to 12 satellites. SiRF is a protocol that GPS software

uses to communicate with GPS hardware. Some preliminary testing with the Holux GPS units shows that it is more sensitive than most other GPS receivers and is therefore a good choice for this project.

3.4.2 Code Design

The Charles River City program is developed in Microsoft's Visual Studio .NET 2003 Environment and is written in the C# language. C# is an object-oriented programming language, and the game is designed using objects and classes. There are five major components in Charles River City: the `GameEntity` class, the `Game` class, the `MainForm` class, the `GPSEngine` component, and the `IR` class.

The `GameEntity` class is the parent class for all the game elements in the game. There are four classes that inherit from the `GameEntity` class: the `Player` class, the `NPC` class, the `Bird` class, and the `WaterStation` class. Each of these children classes contains a method for handling triggered hotspot events, a `Draw` method to display itself on the map, and a `ReadXML` method.

The `Game` class is the object that contains the content for a particular game. It maintains a list of the game's NPC, Bird, and Water Station objects, and their associated interviews or data information. The `Game` class also has a thread that checks every two seconds whether a hotspot event is triggered, and passes the control on to the appropriate game element is one is triggered.

The `MainForm` class deals with the Graphical User Interface component of the game. At the initialization of the game, the `MainForm` class sets up the

serial port and the threads for reading GPS; it sets up the appropriate ports and listeners for handling infrared events; it begins the game timer to keep track of the game time; it sets up the display area for the map and the five tabs, and initializes a new `Game` object to start the game. During the game, the `MainForm` class handles GUI events such as what happens when the player presses a button or a menu item.

The `GPSEngine` component contains three classes, the `SerialPort` class, the `GPSPoller` class, and the `CoordinatesEngine` class. The `SerialPort` class deals with opening the Pocket PC device's serial port and interfacing with the GPS receiver, while the `GPSPoller` class works with threads that polls for GPS data every second and passes it on to a output handler in the `MainForm` class. The `CoordinatesEngine` class converts GPS position into screen coordinates for displaying and tracking the player's movements.

The `IR` class implements a listener to listen for data coming from the Pocket PC device's infrared port, and a sender class that handles the sending of data through the infrared port. Whenever data is received from the infrared port, the `IR` class notifies the `Game` object and passes it the string that was received for further parsing and processing.

Lastly, several smaller classes make up the rest of the game. There is the `Utilities` class, which contains many helper functions, such as definition of the `Date` object used for keeping track of the game time. There are also the various dialog form classes, like the `IntroForm` class, the `NPCForm` class, the `BirdForm` class, and the `WaterForm` class, that get called when a hotspot is

triggered. For example, if the player walks into a bird icon and a bird event is triggered, a `BirdForm` is created and displayed to the player, which allows him to view information about the bird and choose whether or not to collect blood samples.

3.4.3 Game Content Using XML

The content for the Charles River City game is loaded onto the application using an XML file. XML elements define the NPCs, the birds, and the water stations that are to be in a particular game. Since the game elements and certain game parameters are not hard-coded into the program, there is great flexibility in creating different games that can be played using the same application. It is also easy to make changes to a game's content and adjusting parameters like the location of a certain NPC, what events an NPC interview can trigger, and when the start date of the game should be, through changing values in the game's XML file. In addition, since the map of the game is specified in the XML document, it is replaceable and the game can be played in any location a new game might require.

As an example, the following XML code defines an NPC named Samuel Harrison located at the position (75, 120):

```
<NPC>
    <Name>Samuel Harrison</Name>
    <Description>
        Samuel Harrison is a medical student from Harvard.
```

```
    </Description>
    <ImageFile>Program Files\\RiverCityAR\\student.gif</ImageFile>
    <X>75</X>
    <Y>120</Y>
</NPC>
```

Below is the XML code for an interview with Samuel Harrison in time period two by a Medical Doctor role. This interview includes a document, and triggers another NPC to become visible:

```
<DoctorTime2>
    <NPC>Samuel Harrison</NPC>
    <Interview>
        <New>true</New>
        <Time>2</Time>
        <DocName>SARS Document</DocName>
        <DocPath>
            Program Files\\RiverCityAR\\SARSdocument.html
        </DocPath>
        <Health>Temperature: normal.  Blood pressure: normal.</Health>
        <TriggersNPC>Dr. Nathan Jones</TriggersNPC>
        <TriggersBird></TriggersBird>
        <TriggersWater></TriggersWater>
        <ContentCount>2</ContentCount>
```

```
            <Content>
                Sorry I can't talk to you for long since I have a final coming up.
                But here, take this article I've recently read about SARS.  It
                contains some detailed information that might be of help to you.
            </Content>
            <Content>
                You should also talk to Dr. Nathan Jones, one of my professors.
                He is an expert on the subject, and recently consulted with the
                government during the height of the disease in March.
            </Content>
        </Interview>
    <DoctorTime2>
```

As can be seen, the XML method of game content input creates an interface that makes it simple for anyone to design a game.

3.4.4 GPS Calculations

As described in the Code Design section earlier, a special thread polls the Pocket PC's serial port every second for GPS position information during the game. The data from the GPS receiver comes in a series of string representing different information. An example of a reading might look like this:

```
$GPGGA,120757,5152.985,N,00205.733,W,1,06,2.5,121.9,M,49.4,M,,*52
```

Each index (as separated by commas) in the string specifies the following:

0 Format,
1 Time of fix (hhmmss),
2 Latitude,
3 N/S (North or South),
4 Longitude,
5 E/W (East or West),
6 Fix quality (0=invalid, 1=GPS fix, 2=DGPS fix),
7 Number of satellites being tracked,
8 Horizontal dilution of position,
9 Altitude above sea level,
10 M (meters),
11 Height of Geoid (means sea level) above WGS84 ellipsoid,
12 Time in seconds since last DGPS update,
13 DGPS station ID number,
14 Checksum

Only some of this information is used in determining the receiver's location. Therefore, the program needs to parse this GPS string for the relevant information and also make further calculations in order to convert the data into screen coordinates for displaying the player's position on the map.

Initially, a GPS position consists of its latitude and longitude, and the code parses the GPS string for these two numbers (at index two and four, respectively) after every successful read. Next, the conversion from GPS position into screen coordinates takes two steps. First, the GPS coordinate is converted into a 3D point in the earth's 3D coordinate system in which the center of the earth is the origin (See Figure 3.4.1).

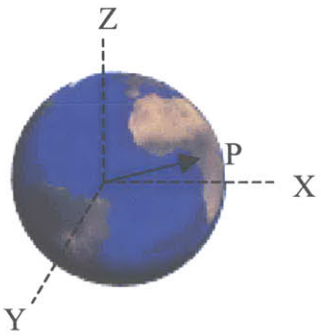

Figure 3.4.1 The earth's 3D coordinate system and the location of player P.

Then, the 3D point is converted into its corresponding 2D game coordinate (x and y) by using the known 3D positions of three other fixed points on the map and some trigonometric calculations. More specifically, we obtain in advance the GPS positions of three fixed points: the lower left corner (LLC), the lower right corner (LRC), and the upper right corner (URC) of the map (See Figure 3.4.2). We then convert these three points into 3D coordinates.

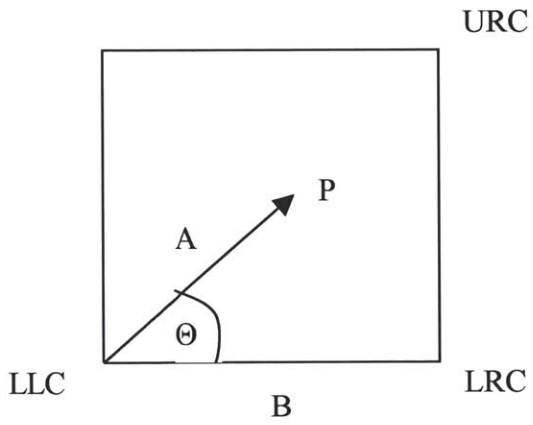

Figure 3.4.2 Calculating the player's position (P) with 3 fixed points.

From LLC and LRC, we can calculate the X-scale of the map:

X-scale = Width of map / Real 3D distance between LLC and LRC

Similarly, we can determine the Y-scale using the points LRC and URC:

Y-scale = Height of map / Real 3D distance between LRC and URC

Then, by finding out what theta (Θ) is, we can obtain the 2D coordinate for the player P using these trigonometric equations:

$$X = \cos \Theta * A * \text{X-scale} \quad \text{and} \quad Y = \sin \Theta * A * \text{Y-scale}$$

where A is the 3D vector formed by LLC and P. To find theta, we can use this trigonometric equation:

$$\cos \Theta = A * B \; / \; |A| \; |B|$$

where A is the 3D vector formed by LLC and P, and B is the 3D vector formed by LLC and LRC. The resulting 2D coordinate from the calculation is the player's position on the screen. If the player has moved, a part of the map will be redrawn to show the update.

4.0 Evaluation

4.1 The Development Process

Initially, this thesis project involved becoming familiar with the development environment: the C# programming language, the .NET Compact Framework [10], GPS technology, and augmented reality simulation games on mobile devices. The Environmental Detectives game was a valuable resource for learning about all of the above. Although Charles River City's code design and implementation was built from scratch, the code from Environmental Detectives was important for understanding the workings of a GPS-based Pocket PC game and for some helpful programming tricks.

As the programming phase of the project progressed, one of the challenges in implementing the Charles River City game and games for mobile devices in general is the hardware limitations of a compact device. The Pocket PC has limited processing power and storage size that must be taken into account in the code design. Therefore, it is important to keep the design simple and the code efficient. Sometimes, tradeoffs have to be made between having more features and working within the limits of the device's processing power and memory size.

As an example, at one point in the implementation process, the game's responsiveness started to lag behind by a few seconds and significantly affected the game play. The reason was traced to the IR listener being always on. The IR listener checks the infrared port every second to see if another device is sending it IR data. As the size and complexity of the program grew, the listener's

polling every second was slowing down the overall game. In order to correct this performance issue, we implemented a menu item that allows the player to turn on and turn off the IR listener each time he wants to receive data rather than having the listener be always on by default.

Testing and debugging is also more difficult with a mobile device application than with a desktop application. At times, it is hard to pinpoint a bug because the game is deployed and run on the Pocket PC separate from the development environment on the desktop. This makes it harder to get feedback about what went wrong. Also, testing the GPS module depended on some uncontrollable factors like the strength of satellite signals, blocking by nearby buildings, and the weather. These are some drawbacks and inconvenience associated with developing a mobile game.

4.2 The Student's Learning Process

The Charles River City game is intended to teach students about scientific investigation and knowledge about modern diseases. There are several valuable lessons that they should gain from the game playing experience.

First, the student is presented with a realistic problem that spans the fields of science, epidemiology, ecology, and politics. The students must learn about all these fields as they explore the game, talking to virtual characters and collecting data. They have to gather clues, sift through abundant information, determine the relevance of each piece of information, and form conclusions just like in the real world. The Charles River City game helps the students develop

their problem solving skills, their analytical skills, and their logical thinking process in a practical way.

The different player roles require that students work with each other to successfully finish the game. Students learn the skill of teamwork through the collaboration. The role-playing feature also simulates the real world in which people specialize in one area and no one person can solve a complex problem such as the one presented in Charles River City. Also, player differentiation based on roles teaches students that different people have different access to information in the real world. For example, an ecologist NPC might be willing to share more information with the Environmental Specialist because of similar backgrounds while a restaurant owner might be reluctant to talk to the Government Health Official for fear of his restaurant being suspected of not meeting health standards.

Next, the students learn about real, plausible health problems that exist today. SARS affected people from the United States through international air travel, while West Nile Virus has been a seasonal epidemic in North America since 1999. The Charles River City game is an innovative way of teaching this material to students outside of the classroom. It can complement the use of traditional teaching channels like textbooks and lectures.

Lastly, Charles River City's augmented reality simulation format should be a fun and refreshing experience for the students. The students have a chance to go outside the confines of their classroom and move around. The game should

also effectively capture the students' attention and increase their interest in learning.

4.3 Trial Run and Observations

At the end of the thesis, we had a test run of the Charles River City game that took place on the MIT campus. It was a scaled down version of the actual game, with fewer virtual characters and the absence of the SARS storyline. There were three players, each representing one of the three player roles (See Figure 4.3.1). The keypad was used instead of GPS for navigation, and the players moved around the MIT campus while using the keypad to simulate the GPS function. Some very useful feedback was obtained from the trial run.

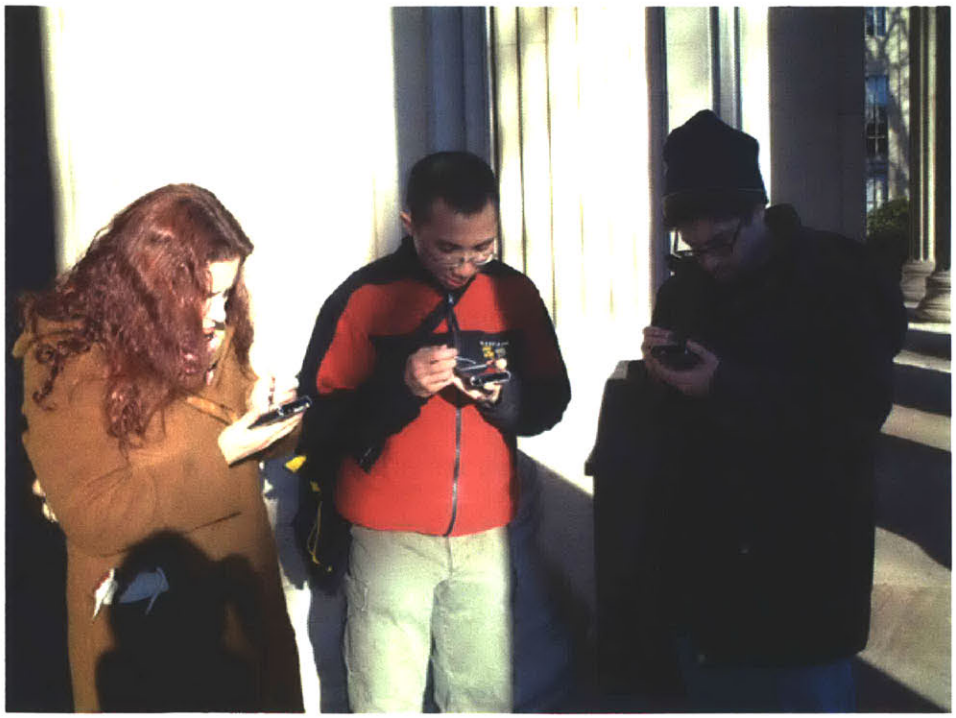

Figure 4.3.1 The three participants at the beginning of the test run.

Overall, the Charles River City game was thought to be fun and challenging. The participants especially liked the different player roles in the game, as it encouraged teamwork and allowed players unique access to different information. As one of the participants said, "It's nice to have a team and work together, and being collaborative; I felt like I want to share information right away, because it felt like we're all working together against the clock."

Figure 4.3.2 Two players exchanging information through IR.

With the use of walkie-talkies, the players were able to share information, throw out hypotheses, and plan next moves immediately after new information is acquired from an interview or a data sample. The players also thought that the different roles made the game realistic because like in real life, different people often have different access to information. Additionally, they thought that "the different roles made the game more interesting and fun; and each person's distinct role made it worthwhile to go back and interview someone."

Figure 4.3.3 Players using a walkie-talkie to communicate with others.

Although the participants thought that the different player roles greatly added to the playing experience, there also made some suggestions that could further improve the involvement of different player roles in the game play. The player who took on the Medical Doctor role felt that she would benefit from having some kind of fact sheet containing basic medical knowledge about diseases and symptoms. Possession of that background information would better simulate the Medical Doctor's unique expertise and increase her contribution to the investigation process. The Environmental Specialist player, on the other hand, suggested that the data sampling process should involve more analysis. For example, rather than receiving the results to only one specific type of lab test at a water station, the player could perhaps be given results to different types of testing and then determine which of the data is relevant.

With regards to the graphical user interface, the feedback was positive overall. Despite the small screen, the map and the way that the icons were displayed were thought to be clear and intuitive. There did no seem to be any problems with performing any of the functions of the game, such as sending and receiving IR or reading through an interview. A suggestion was made concerning the IR exchange that more than one interview may be selected and sent at once instead of having to send each interview one at a time.

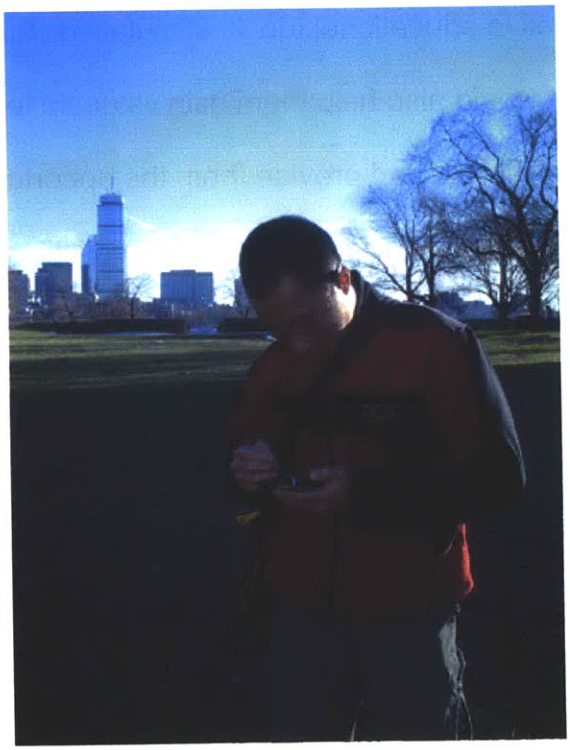

Figure 4.3.4 One of the players working with the small Pocket PC screen.

On the learning process in Charles River City, the participants' comments matched the goal of what this thesis was trying to achieve. The goal was to give the player a hands on experience in learning about epidemiology and scientific

investigations. As one participant said, "I had a first hand feel of what the investigation process and the diseases are all about, which otherwise I would only have read about from a textbook." The mission to make a recommendation to the mayor at the end of the game also posed an interesting challenge for the players. There were many aspects that need to be considered when making a recommendation, such as what is the appropriate policy in terms of politics and the public's welfare.

In conclusion, the test run had shown that the Charles River City game would be an effective educational tool in stimulating students' interest in learning about science. It would also help them gain valuable teamwork skills, challenge them to think analytically, and provide them the opportunity to experience first hand solving an epidemiological problem with realistic issues.

4.4 Comparison with MUVEES River City

Since Charles River City is motivated by MUVEES River City, it is interesting to compare and contrast the two games as teaching tools. Both games have a similar story background and challenge, but their different form factors make the learning experience different.

MUVEES River City is an indoor multiplayer server game, whereas Charles River City is an outdoors, location-based, augmented reality simulation. Since MUVEES River City is played over a two-week period, it can be integrated as a unit into a class's curriculum. In addition to interacting with the virtual world, students have to keep a journal describing events, progress, and results that the

teacher can grade. Students also have a chance to do outside research with the extra time to help them with their solution process. Charles River City, on the other hand, is only two hours long probably played during a class field trip. Students would have to gather and process information in this short period of time. Therefore, the knowledge that the students gain from playing MUVEES River City is probably more in depth and the challenge more complex than in Charles River City.

There are different types of interactions within both the MUVEES River City game and the Charles River City game. In the first version of MUVEES River City, interaction between the player and the NPCs is minimal; the player is only allowed to overhear the NPCs' conversations. An instant messaging function integrated into the game allow players within a team to communicate with each other and emote their feelings with preset buttons that sends text such as "I feel happy". There is no player role differentiation and all the players in a team see the same information. In Charles River City, player-NPC and player-player interactions play a bigger part in the game. The players actively talk to the NPCs and can even measure an NPC's vital signs after an interview. Players can also pass documents and interviews to each other to further the development of the game's story line. In conclusion, more types of interaction exist in the Charles River City game than in the MUVEES River City game, allowing the student to be more involved in the learning process and providing him with a more realistic simulation.

5.0 Summary and Future Work

Charles River City is an augmented reality simulation game designed to be an innovative teaching tool that engages middle school to high school aged students in learning science. It is a mobile, outdoors game that makes use of Pocket PC devices and GPS technology. The game design of Charles River City builds on the experience of an earlier augmented reality simulation game called Environmental Detectives and a desktop, server-based virtual reality simulation game called MUVEES River City.

This thesis has implemented and established the basic design and framework for the Charles River City game. However, more features and functions can be added to the game in the future to continually improve the student's playing and learning experience. For example, there can be more interaction between the players and the game elements. One way is to allow the players to potentially become infected with one of the illnesses if they behave in a careless way. Additionally, they can possibly pass the disease on to another player during one of their IR exchanges. This type of interaction adds more realism to the game as the players may risk getting sick in the process of searching for a disease's source.

In terms of the user interface, more features can be added to the map's display. For example, we can add such features as scrolling and zooming capabilities to allow the player to view more details on a larger and higher resolution map. In addition to passing around documents, players may also receive video and audio files from the NPCs in future implementations. Lastly,

we can gain more insights into the pros and cons of an augmented reality simulation game compared to a desktop virtual reality game by having students play both the MUVEES River City game and the Charles River City game and then getting their feedback about each game.

The application of augmented reality simulation handheld games to the middle or high school educational curriculum is still a relatively new area of research. As these games are introduced to more and more classes and more feedback from teachers and students are obtained, they will continue to prove to be useful resources that effectively teach students practical problem solving skills that at the same time stimulate their interest in learning science.

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Appendix: Trial Run Game Content

Non Player Characters

Julia Washington, M.D.
Cambridge Hospital

Ed Mansfield
Regional Department of Health Statistics and Records

Eileen Chang
Scientist/Advocate at Charles River Watershed Agency

Big Jim Donahue
Resident, Iota Lambda Lambda Fraternity House

Gene Rodriguez
Mass. Office of Public Health

Salvadore Cappalatto
Resident, Cambridge Home for the Aged

Nurse Francis White
Nurse Practitioner, University Health Services

Female Jogger
Running along the Charles

Birds

Bird 1
The large, black bird on the ground appears to be dead.

Bird 2
The blue bird on the ground appears to be dead.

Water Stations

Water Station 1
CRWA River Sampling Station #126
Time 1: E. coli colonies per 100 mL – 80
Time 2: E. coli colonies per 100 mL – 180

Time 3: E. coli colonies per 100 mL – 20

Water Station 2

CRWA River Sampling Station #127
Time 1: E. coli colonies per 100 mL – 240
Time 2: E. coli colonies per 100 mL – 180
Time 3: E. coli colonies per 100 mL – 30

Water Station 3

CRWA River Sampling Station #128
Time 1: E. coli colonies per 100 mL – 240
Time 2: E. coli colonies per 100 mL – 170
Time 3: E. coli colonies per 100 mL – 40

Water Station 4

Various old tires and buckets appear full of water.
Time 1: Mosquito eggs and larvae appear to be present.

Water Station 5

Birdbath statue containing some water.
Time 1: Mosquito eggs and larvae appear to be present.

Interviews

Time Period 1

Medical Doctor Player Role

Female Jogger:

"Can't believe all this rain we've been having. Sure makes running outside a drag. I can't remember a rainier spring. I see you eyeing the river. Yeah, it does look higher up on the banks than usual. Gotta go. See ya!"

Nurse Francis White:

"Have I noticed anything unusual lately? Well, we see lots of strange stuff serving a college community. Crazy college kids. Anyway, few days ago we had this group of college boys come in, all in a group - maybe 7 or 8 of them, with some pretty bad symptoms: Severe stomach cramps, bloody diarrhea, nausea, vomiting. Nasty business."

"It looked like maybe food poisoning or maybe E.Coli with the symptoms and the group all at once. Kept em here for a few hours and then sent the gang home to rest. But it struck me as funny that they wouldn't tell us anything about how they got sick. Usually people say, "Oh it must've been that BBQ," or something like that. But these guys kept tightlipped and kept shooting each other shady glances."

"I'm not a betting woman, but I'd wager there was something funny going on with those guys in Iota Lambda Lambda. Good thing is, for most people, E. Coli - and I'd guess that's what they had - isn't really dangerous. People usually get better on their own in a week or so. I told 'em to drink a lot of fluids and take it easy. Now, if they were young kids, or elderly, or a pregnant woman it'd be different. But for them it's not too serious. They'll be fine."

Big Jim Donahue:

"You're not from the University? Or the police? Well, since you're a doctor you have to keep this confidential, right? Ok, I'll tell you what happened. We've done it for years now. Our annual end-of-semester tradition. We went for our midnight swim in the Charles. You know, skinny dipping."

"I didn't want to tell them that because the University's been cracking down on hazing. We were just horsing around a little. Maybe drinking a little. But the next day, a bunch of us got really sick. Some guys thought it might have been from the BBQ. But now that I think about it, I didn't eat anything there and I got sick too. Huh. I wonder if swimming in the river made us sick?"

Gene Rodriguez

"West Nile Virus? Sure, it's a potential problem. Best thing folks can do to avoid WNV is to keep away from mosquitos. That's how WNV gets to humans. Wear long sleeves, stay inside during early morning and dusk - peak mosquito feeding hours, and use DEET repellant."

Environmental Specialist Player Role

Female Jogger:

"Can't believe all this rain we've been having lately. Sure makes running outside a drag. I can't remember a rainier spring. I see you eyeing the river. Yeah, it does look higher up than usual."

"You said you're an Environmental Scientist? And you want to know if I've seen anything funny around the river lately? Nothing comes to mind. But you might want to talk with my friend Eileen Chang. She works with the Charles River Watershed Association - the CRWA."

"Hey, come to think of it, I did see a dead birds back behind me on the path. Been jogging here for years and I've never seen anything like that before."

Eileen Chang

"So you're looking into environmental factors that could be making people sick? Well, here at the CRWA, we monitor the Charles River water quality. While it used to be a lot worse, the Charles still has significant levels of pollution. There are 35 towns and cities, that's 308 square miles, that empty in the Charles River. So there's lots of places for things to find their way into the river."

"Our routine sampling tells us that germs from sewage and water runoff (mainly from rainfall), still contaminate the river to varying degrees. So after a big rainstorm, for example, it's not uncommon to find elevated levels of things like E. Coli 0157:H7 which, if swallowed by humans, could cause serious diarrhea. I think there's a point right along the river nearby where some runoff empties in. We sometimes see elevated contaminant readings just downstream from that point. But for the most part, people don't get their drinking water from the Charles."

"It's important to notice how much water readings fluctuate though. You really have to be vigilant about testing water quality regularly. You might want to go check our sampling stations yourself - there are some right along the river. For E. Coli, the Massachusetts Department of Public Health counts levels exceeding 126 colonies per 100mL of water to be poor water quality. I can tell you, I wouldn't drink it."

Nurse Francis White:

"Have I noticed anything unusual lately? Well, we see lots of strange stuff serving a college community. Crazy college kids. Anyway, few days ago we had this group of college boys come in, all in a group - maybe 7 or 8 of them, with some pretty bad symptoms: Severe stomach cramps, bloody diarrhea, nausea, vomiting. Nasty business."

"It looked like maybe food poisoning with the symptoms and the group all at once. Kept them here for a few hours and then sent the gang home to rest. But it struck me as funny that they wouldn't tell us anything about how they got sick. Usually people say, 'Oh it must've been that BBQ,' or something like that. But these guys kept tightlipped and kept shooting each other shady glances. I'm not a betting woman, but I'd wager there was something funny going on with those guys in Iota Lambda Lambda."

Big Jim Donahue:

"An Ecologist? Why are you asking me all these questions? You know what? I'm sorry but I gotta go. Bye."

Julia Washington, M.D.

"I actually treated a case of WNV last year. According to CDC estimates, roughly 80% of cases actually don't show symptoms. Most of the other 20% of infected patients show mild symptoms including fever, headache, nausea, vomiting, sometimes swolen lymph glands or a skin rash on the chest, stomach and back. There's no treatment, but most people get better on their own."

"But a few cases, like the one I saw, show severe symptoms. High fever, headache, stupor and disorientation, coma, tremors. The symptoms can last several weeks and neurological effects can be permanent."

"Here's a fact sheet from the CDC. It explains how this disease spreads, who's at high risk, and the severity of illness. Hope this helps. Good luck."

"Hmmm...now you've got me thinking. An elderly woman was here recently complaining of swarms of mosquitoes near her apartment building - the Cambridge Home for the Aged. Maybe you could look into it."

Salvadore Cappalatto:

"Happy to help if I can. Nice to be appreciated. Listened to. Well this seems like it's gonna be a long, rainy summer. With all the rain lately, seems like there's already mosquitoes everywhere."

"I keep telling the maintenance guys to dump the water out of those old tires near the dumpster, but they just ignore me like everybody else. But sittin out back here, it seems you can't grab some fresh air without gettin' a few more bites."

"I also been telling 'em to fix the screens in my windows since I like to sleep with some air, but they get through the damn holes and buzz in my ears all night too. Can't get my beauty sleep. Can you help me walk inside? I'm feeling a little dizzy. Do you think a doctor could come take a look at me?"

Government Health Official Player Role

Female Jogger:

"Can't believe all this rain we've been having. Sure makes running outside a drag. I can't remember a rainier spring. I see you eyeing the river. Yeah, it does look higher up on the banks than usual. Gotta go. See ya!"

Nurse Francis White:

"Have I noticed anything unusual lately? Well, we see lots of strange stuff serving a college community. Crazy college kids. Anyway, few days ago we had this group of college boys come in, all in a group - maybe 7 or 8 of them, with some pretty bad symptoms: Severe stomach cramps, bloody diarrhea, nausea, vomiting. Nasty business."

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BBQ," or something like that. But these guys kept tightlipped and kept shooting each other shady glances. I'm not a betting woman, but I'd wager there was something funny going on with those guys in Iota Lambda Lambda."

Gene Rodriguez:

"West Nile Virus? Sure, it's a potential problem. It's been an extremely wet Spring. That's a bonanza for mosquitos. Water everywhere for 'em to breed in. WNV is seasonal and summer's peak season for mosquitoes and WNV cases."

"Frankly, between you and me, WNV is a serious health threat. It was unknown in the western hemisphere until 1999 when it appeared in NY causing an epidemic of encephalitis and meningitis in the NY metro area. 59 cases, 7 deaths. Now it's spread across the U.S. and seems to get stronger every year. Prevention is all about mosquito control. People can eliminate standing water, repair screens."

"The government can also spray designated areas to kill populations of mosquitoes. Hey, you should talk to my friend Ed over in Records. He's on vacation but he'll be back next week. He'll show you the numbers. The numbers don't lie."

Julia Washington, M.D.:

"I actually treated a case of WNV last year. According to CDC estimates, roughly 80% of cases actually don't show symptoms. Most of the other 20% of infected patients show mild symptoms including fever, headache, nausea, vomiting, sometimes swolen lymph glands or a skin rash on the chest, stomach and back. There's no treatment, but most people get better on their own."

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"I keep telling the maintenance guys to dump the water out of those old tires near the dumpster, but they just ignore me like everybody else. But sittin out back here, it seems you can't grab some fresh air without gettin' a few more bites."

"I also been telling 'em to fix the screens in my windows since I like to sleep with some air, but they get through the damn holes and buzz in my ears all night too. Can't get my beauty sleep. Can you help me walk inside? I'm feeling a little dizzy. Do you think a doctor could come take a look at me?"

Ed Mansfield:

"Yeah, just got back from vacation in Florida. Muggy as anything down there. So you want records on WNV? You came to the right place. I can tell you some numbers to put things in perspective."

"First of all, we track lots of data here: birds, humans, horses, mosquitoes - anything that tests positive for WNV. Let's focus just on Middlesex County. In 2003, we had 15 people who tested positive for WNV in Massachusetts, 5 in Middlesex County. This year, we've already got 4 probable cases and it's only June."

"We also routinely track dead birds which test positive for WNV. In Middlesex County alone, we recorded 95 positive birds in 2003. This year, we've already tracked 44 in Middlesex county

and we're not even 1/3 into the season. Statistically, we're way ahead of where we were last year. It looks like we're on a growth curve. Kinda makes you think. Oh, that smell? It's the DEET I'm wearing."