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USABILITY TESTING OF THE M.A.E.G.U.S. SERIOUS GAME

For the degree of Master of Science

Is approved by the final examining committee:

David Whittinghill

Mihaela Vorvoreanu

Victor Chen

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Approved by Major Professor(s): David Whittinghill

Approved by: Mihaela Vorvoreanu 04/21/2014

Head of the Department Graduate Program Date

USABILITY TESTING OF THE M.A.E.G.U.S. SERIOUS GAME

A Thesis

Submitted to the Faculty

of

Purdue University

by

James He

In Partial Fulfillment of the

Requirements for the Degree

of

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ABSTRACT

He, James M.S., Purdue University, May 2014. Data Visualization of Simultaneous Multi-Variate Systems. Major Professor: David Whittinghill.

Interpreting raw data in serious games and simulations can be a time consuming and uninteresting task without visualizations. This study proposes one possible solution for an interface that incorporates data visualizations for Whittinghill and Nataraja's (2013) MAEGUS simulation, a serious game used to increase the retention of wind energy and solar energy concepts in students, while still being fun. After the interface was designed and developed, a think aloud usability test was conducted to answer the following research questions: how do students use a series of information visualizations to operate a multi-variate game-based simulation and what are some the usability issues the students face in the simulation? A thematic analysis was then conducted to document and organize the responses.

CHAPTER 1. INTRODUCTION

Sight and visualization are two of the key senses for information understanding and decision making. This thesis presents one possible solution to improving the MAEGUS simulation presented by Nataraja and Whittinghill (2013) with an interface incorporating data visualization techniques. This chapter provides an overview into the research project covering the scope, significance, statement of purpose, and research question. In addition the assumptions, limitations, and delimitations are provided to further define the scope.

1.1 Scope

The user interface and data graphics will be built in Unity (Nataraja et al., 2013) concurrently during the development of the MAEGUS simulation by Nataraja and Whittinghill (2013). The user interface is created based upon existing data visualization concepts and techniques. One of the focuses of this interface is clearly communicating data through visualization so that the user can effectively operate the simulation. Data processed for visualization is primarily from sustainable energy technologies such as wind turbines and solar arrays.

1.2 Significance

The primary contribution of this research is an empirical examination and development of an interface with existing data visualization techniques to improve the usability of complex simulations and games.

1.3 Statement of Purpose

The focus of this study is the improvement of Nataraja and Whittinghill's (2013) MAEGUS simulation by creating a user interface that has been designed based upon existing data visualization concepts and techniques. Established research on data visualization and user interfaces form the basis of the design of an interface that will not only communicate information clearly to the user, but also easily enable their gaining mastery of the interface. The MAEGUS simulation runs multiple concurrent systems. Therefore a user interface that can effectively present information from multiple dynamic data sets is essential. The interface must not only display information, but also provide an intuitive mechanism for the user to manipulate the parameters of the underlying systems in order o effectively operate the simulation.

1.4 Research Question

How do students use a series of information visualizations to operate a multi-variate game-based simulation and what are some the usability issues the students face in the simulation?

1.5 Assumptions

The assumptions of this study are the following:

- Subjects will have the basic computer skills required to operate a windows based game using the mouse and keyboard.
- Subjects will have access to a quiet and well-lit environment.
- Subjects will have access to a windows computer that can run Unity smoothly.
- Subjects will be honest in answering survey and interview questions to the best of their abilities.
- Subjects understand the assigned tasks.
- Subjects are not vision impaired.
- Subjects can interpret basic graphs.
- Subjects have some basic knowledge of how wind turbines and solar panels generate energy.
- Subjects will offer up to one hour of their time for the usability assessment.

1.6 Limitations

The limitations of this study are the following:

- The study is limited to college students.
- The researcher cannot control the students from having interface preferences based on disabilities.
- The interface is specifically made for the Windows operating system.

- The program is limited to mouse and keyboard input.
- Sustainable energy concepts are limited to wind turbines and solar arrays.
- The development of information visualizations is determined by the variables and concepts provided by the MAEGUS educational research component.
- Development does not include game settings or options changing.
- Development acts as a functional prototype.

1.7 Delimitations

The delimitations of this study are the following:

- Coal and oil energy sources will not be included in the study.
- The study will not argue which specific data visualization was better.

1.8 Definitions of Key Terms

MAEGUS - Measuring Alternative Energy Generation via Unity Simulation (Nataraja & Whittinghill, 2013).

Visualization - the communication of information using graphical representations (Ward, 2010).

Sustainable Energy - Renewable forms of energy such as wind or solar energy. These forms of energy are sustainable and in most cases considered infinite. Sustainable energies are also called alternate energy as they are alternatives to non-renewable resources such as coal and oil (Acikgoz, 2011).

1.9 Summary

This thesis proposes a solution for assisting players in a multivariate system using a combination of existing information visualization techniques. In order to understand how to design and evaluate a unique interface incorporating existing information visualization techniques for the MAEGUS simulation, a literature review was conducted, which is detailed in the next section.

CHAPTER 2. LITERATURE REVIEW

Interpreting raw data in simulations can be a challenging task for users without visual cues. This literature review provides a base of knowledge for developing a user interface that can effectively present information from multiple dynamic data sets for Nataraja and Whittinghill's (2013) MAEGUS simulation. The MAEGUS simulation is a Unity-based serious game attempting to increase the retention of wind energy and solar energy concepts in students. This paper focuses primarily on research material that covers visualization frameworks of energy data as well as supplementary research in educational games, information visualization, and user interfaces. The first portion of this paper provides a brief overview of the MAEGUS simulation as well as a comprehensive look at information visualization. Existing visualization frameworks for energy simulations and education games are then analyzed to bridge the gap between the user and raw data.

2.1 MAEGUS

MAEGUS (Measuring Alternative Energy Generation via Unity Simulation) is a Unity-based sustainable energy simulation created by Nataraja and Whittinghill (2013) that is intended to serve as an educational tool to promote energy literacy. This simulation is presented in the form of a serious game where the player takes the role of a city planner entrusted with providing energy to his or her city by means of sustainable energy technologies. The game focuses on placing wind turbines and solar arrays to generate energy in a physically accurate fashion using simulated weather data. Players are presented with scenarios that require certain energy output goals while working within a budget. Currently MAEGUS's physics engine and implementation is being developed by Nataraja, but there is still a need for an interface that users can easily view to interpret generated data to make correct decisions on how to operate the simulation.

2.2 Game Data

The first step to the development of the interface is to understand the variables for the game and the concepts that need to be presented for wind and solar technologies. The game is a turn based single player strategy game where the player builds wind turbines and solar arrays atop a hexagon map with varying terrains. The goal of the game is to reach a high score of energy production by cleverly building or upgrading the clean energy technologies and properly managing funds per turn. The game revolves around the following variables:

- **Funds:** Funds are the currency used in the game that allow the player to build or upgrade wind turbines and solar arrays. The player receives funds per turn, but can also increase these funds through energy goals.
- **Building space:** Although the map for the game is quite large the player can only initially build in a preset area. As the game

progresses and the player generates more energy the area available for building increases. This is also achieved by reaching energy goals.

- **Turns:** The game revolves around a preset amount of turns so each turn must be carefully thought out in order to achieve the highest score. The less turns it takes to achieve energy goals the earlier the player can receive more funds and more building space to achieve higher energy goals.
- **Energy Goals:** Energy generated by the wind turbines and solar arrays add to the energy goal meter. Once the meter is filled the funds per turn will be multiplied and the building space will increase allowing the player to build on more hexes. The cycle continues with another energy goal given to the player which can be creative and add to the story aspect of the game; this is talked about more in the GEL and flow experience part of the paper.

These variables provide a general look at how the game functions, but research needed to be done to explain how wind and solar technologies affect these game variables. The next sections in this literature review explains what concepts in wind and solar technologies are transferred into the game.

2.3 Wind Turbines

This section of the literature review analyzes the different environmental factors and technical factors that affect a wind turbines energy output. Wind energy is calculated using the formula below (Belu & Koracin, 2012).

$$\sum \frac{1}{2} pAv^3C$$

Figure 2.1 Wind Formula

This formula can be broken up into the following variables: swept area of the rotor blades(A), air density(p), the wind speed(v), and the power coefficient of the generator (Cp) with the dependent variable being power generated (P) (Belu & Koracin, 2012). The variables of rotor blades and coefficient of the generator are technical factors and the variables of air density and wind speed are environmental factors. By breaking these variables into these two groups the techniques to appropriately represent these variables visually in the game can then be determined. The technical aspects refers to the physical model of the wind turbine and can be represented in the game by visually changing the in game model of the wind turbine. This thesis proposes using an abstract version of representing the environmental data through information visualizations. This design choice will be covered further down in the literature review.

Several other variables can affect wind energy output including the wind direction and distance between turbines (Chen, Wang, Liu, Chen, Li, & Guan, 2012). Because wind direction is such an important factor to wind energy generation, modern wind turbines will be able to detect wind direction and automatically change to that position. Another important factor that can affect energy generation is the distance between turbines. To avoid the wake affect and to ensure each unit around the topography is the same with average wind speed, wind turbines should be placed 500 meters away from each other (Chen et al., 2012).

2.4 Solar Arrays

The other major sustainable technology used in this serious game is the solar array. This section of the literature review analyzes the technical factors that affect a solar array energy output. These solar arrays, also called photovoltaic trackers, are scalable in size by the number of panels in an array (Koussa, Cheknane, Hadji, Haddadi & Noureddine, 2011). Two primary factors affect the measurement of solar power from solar arrays which are the estimated wattage of the panels and the number of panels in the array (Koussa et al., 2011). Some other factors that will affect the solar array is the angle of incidence and material of the panels. The angle of incidence is extremely important to how a solar array gathers, titling to optimally gather sunlight. Optimal tilt will be affected by the sun's location and weather patterns (Koussa et al., 2011; Mehleri, Zervas, Sarimveis, Palyvos & Markatos, 2010). Varying materials for solar arrays will also affect solar energy generation because of varying efficiencies of photovoltaic absorption (Green, 2013).

2.5 Information Visualization

This thesis defines visualization as the communication of information using graphical representations (Ward, 2010). Pictures have been used as a mechanism for communication since before the formalization of written language. A single picture can contain a wealth of information that can be processed more quickly than a comparable page of words (Ward, 2010). Pictures can also be independent of local language; a graph or a map may be understood by a group of people with no common language (Ward, 2010).

Visualization is a vital asset for communicating data effectively to the user in serious games by allowing them to make sound judgments and decisions. This importance is evident through the ideas of data distortion and human interpretation. Data distortion comes from the ability to visually distort the truth in data. User interpretation or human interpretation is a very real and integral part of specific decision-making processes. This idea emphasizes that it is not only the visualization that is key in presenting data well, but that user preferences are heavily involved (Ward, 2010, p.5). In the process of developing the user interface for MAEGUS, it is important to integrate these two ideas so that the user can soundly make decisions.

Data graphics will be used for this study, which visually display measured quantities by the combined use of points, lines, a coordinate system, numbers, symbols, words, shading, and color (Tufte, 2001). Modern data graphics can do much more than substitute for small statistical tables. At their best, graphics are instruments for reasoning with quantitative information (Tufte, 2001). Tufte also states that often the most effective way to describe, explore, and summarize a set of numbers, even a very large set, is to look at well designed data graphics (Tufte, 2001).

In *Interactive Data Visualization* by Matthew Ward (2010) he states that a new visualization most often begins with an analysis of the type of data available for display and the type of information the viewer hopes to extract from or convey with the display. At a high level view, the visualization process flows from data to symbolic representation, to images in the computer, to images on the display and finally to the user (Ward, 2010). Tufte also argues that there is a set of guidelines or requirements that graphical displays should meet, which are the following (Tufte, 2001):

- show the data
- induce the viewer to think about the substance rather than about methodology, graphic design, the technology of graphics production, or something else
- avoid distorting what the data has to say
- present many numbers in a small space
- make large data sets coherent
- encourage the eye to compare different pieces of data
- reveal the data at several levels of detail, from a broad overview to the fine structure

- serve a reasonably clear purpose: description, exploration, tabulation, or decoration
- be closely integrated with the statistical and verbal descriptions of a data set

By following these guidelines, graphics can reveal data (Tufte, 2001).

The application of these guide lines in MAEGUS is visible when considering how various visualizations in the interface can help the player. At the end of the day,

> the representation of the data is the way you decide to depict data through a choice of physical forms. Whether it is via a line, a bar, a circle , or any other visual variable, you are taking data as the raw material and creating a representation that best portrays its attributes.
> (Kirk, 2012, p. 17).

2.5.1 Considerations For Visualization Choice

This section talks about considerations for the choice of the visualization in this serious game. The considerations form a guideline for choosing the correct visualization to convey the data accurately and appropriately for the system. Kirk proposes the following tips:

- Choosing the correct visualization "method" for the stories we're telling
- Accommodating the physical properties of your data
- Facilitating the desired degree of precision
- Creating an appropriate metaphor to depict our subject stylistically

(Kirk, 2012, p.84).

These tips can then be applied when designing the appropriate interface tools and visualizations that assist in delivering information to the player. Each tip can apply to different aspects of the game, such as the consideration for facilitating the desired degree of precision may play a role in the difficulty of the game by increasing or decreasing the player's level of uncertainty.

2.5.2 Overviews

The field of information visualization is concerned with generating interactive, visual representations of information spaces to amplify user cognition (Card et al., 1999; Hornbæk & Hertzum, 2011). A key goal of many information visualizations is to provide a compact representation of the information space so as to assist users in thinking about and navigating that space (Hornbæk et al. , 2011). Developing data graphics in a compact space concurrently with a real time simulation that requires decision making can be a difficult task without the notion of overview.

Hornbæk et al. (2011) notes that within information-visualization research the notion of an overview has been extremely important and has many benefits to its users. Greene et al. (2000) argued that a good overview ‘‘provides users with an immediate appreciation for the size and extent of the collection of objects the overview represents, how objects in the collection relate to each other, and, importantly, what kinds of objects are not in the collection’’ (p. 381). Hornbæk et al. (2011) also comments that there are at least two uses of the term overview front in literature where one focuses on users gaining an overview of the information space, referred to as overviewing, and the other focusing on overviews mainly being a user-interface component, referred to as overview.

Hornbæk and Hertzum conducted a literature review of 60 papers to understand the definition of overview and how it is used in information visualization. Together they developed a model of overview that incorporates the most important aspects of overview into a unified taxonomy. The short form of this model is:

> Overview is an awareness of [an aspect] of an information space, acquired by [a process] [at a time], useful for [a task] with [an outcome], and provided by a [view- transformed] [visualization].
> (Hornbæk et al., 2011, p. 511).

Hornbæk et al. (2011) explains that in the model "the overview is tied to an object; it is an awareness of something. The model also describes how and when an overview is acquired and what kinds of task and outcome it may support and provide" (Hornbæk et al., 2011, p. 511). The conclusion from their taxonomy was that "an overview is a display that shrinks an information space and shows information about it at a coarse level of granularity" (Hornbæk et al., 2011, p. 522). At the end of Hornbæk et al.'s (2011) paper they bring up relevant concerns in their research. These four concerns that are extremely relevant to the MAEGUS simulation interface research are as follows (Hornbæk et al., 2011, p.522):

1) The distinction between a technical and a user-oriented sense of overview raises the important research question to what extent overviews support users in overviewing an information space.

2) Whether and, if so, how overview definitions and designs can be extended to incorporate active and ongoing creation of an overview. The author suggests that answering this question implies building stronger links between research on information visualization and situational awareness.

3) The tasks and measures used for studying overview are incomplete and limit the possibilities for integrating research findings across studies.

4) The relation between overview and detail needs further work. Resolving this issue requires more knowledge about how different overview designs are useful for different kinds of task, about the relative contributions of the global and local features of a visual scene in creating an overview, and about the role of interaction in overviewing.

Answering elements from these four concerns will form part of the base for the user interface in the MAEGUS simulation and improve the decision making experience.

2.6 Visualization-based Analysis of Gameplay Data

The importance of analyzing player behavior and using the data to improve design decisions has become a popular issue for game developers in recent years. Wallner and Kriglstein (2010) argue that " instrumentation became popular in recent years to unobtrusively obtain the detailed data required to thoroughly evaluate player behavior. To make sense of the large amount of data, appropriate tools and visualizations have been developed" (p. 143). Evaluating player behavior through visualization not only provides data for game developers to readjust designs, but also provides the player with data that may improve their decision-making.

Wallner et al.'s literature review shows that in many cases visualization tools are created for a specific game or genre. They also comment that game data is presented from two perspectives: 'local' and 'global' visualization (Wallner et al., 2010, p. 147). Local visualization allows an analysis of the positions on the players in the map through color coding icons and global visualization focuses on representing statistical information. For the MAEGUS simulation, local visualization will focus on placement of windmills and solar arrays. It is vital for the player to understand how location can affect optimal windmill and solar array placement in the MAEGUS simulation. Global visualization in MAEGUS will focus on providing the user with statistical data such as energy generation through visualization.

2.6.1 Representation in Visualization-based Analysis of Gameplay Data

Wallner et al.'s literature review also shows that visualizing game metric data can be classified in to five sub categories: charts and diagrams, heat maps, movement visualization, self-organizing maps and node-link approaches. Each sub category is listed with a definition and application, to show its usefulness in different kinds of analysis tasks, in the following list (Wallner et al., 2010, p. 148):

1) **Charts and Diagrams:** These are useful for solving specific questions that have to be answered. They are used in almost every gameplay analysis tool to present quantitative data in one form or another.
2) **Heat Maps:** These are commonly used for visualizing game play metrics that can be mapped to a specific coordinate.
3) **Movement Visualization:** When creating a game, designers will assume that players will interact with the game in certain ways. If these assumptions fail for various reasons (e.g., players getting lost or dying repeatedly) it is important to understand why this is the case. movement visualization focuses on visualizing the constantly changing position and orientation of the player's interactions.
4) **Self-organizing Maps:** These are a type of artificial neural network that produces a low-dimensional (typically two-dimensional), discretized visualization of a high-dimensional input space by grouping similar data items together, akin to multidimensional scaling. This information is normally generated with nodes in a rectangular grid.
5) **Node-link Approaches:** Node-link representations have been mainly used for abstract or high-dimensional data, which cannot be visualized in spatial relationship to the virtual environment. Different visual properties like size and color are used to emphasize highly visited game states or to reflect the probability that a player who reached a state

eventually completed the level successfully. Such graphs are valuable for many research questions because they allow the user to observe sequences of actions.

Although Wallner et al. does not define a single solution to visualize all kinds of gameplay data, several elements described can be applied to the construction of the MAEGUS simulation interface.

2.7 Exploring Game Enhanced Learning

GEL (Game Enhanced Learning) can be considered an emerging research topic in the field of Technology Enhanced Learning (de Freitas, Kiili, Ney, Ott, Popescu, Romero, & Stanescu, 2012). De Freitas et al. (2012) states that

> "Serious Games are widely regarded as effective tools for practicing soft skills like problem-solving, decision making, inquiry, multitasking, collaboration, and creativity. They also offer a new standpoint for studying and evaluating the potential of immersive learning environments and for testing the pedagogical value and effectiveness of a number of emerging educational approaches" (de Freitas et al., 2012, p. 289).

In the study, De Freitas et al. outlines that GEL seeks to gain a deeper understanding of the following (de Freitas et al., 2012):

- The main aspects continuing to hinder more widespread use of serious games for educational purposes, at least informal educational settings;

- The keys to increasing the educational effectiveness of serious games and thus broaden their use;
- the role of the different actors in game based learning processes (e.g. Individual learners, learner groups, teachers, developers, virtual agents)

(de Freitas et al., 2012, p. 290).

2.7.1 Design Principles for Flow Experience in Educational Games

The MAEGUS simulation's intent is to improve energy literacy and increase the retention of energy concepts in its players. Understanding the design principles of effective educational games that incorporate learner engagement will be integral to the development of MAEGUS.

Csikszentmihalyi was the founder of Flow theory, having written the book *Beyond Boredom and Anxiety* in 1975 which talks about how to balance boredom and anxiety to create an engaging experience (Csikszentmihalyi, 1975). Flow theory is one foundation that can be used to design appealing and effective educational games. Kiili, Freitas, Arnab, and Lainema (2012) proposed a framework that provides:

> The principles for good educational game design, based upon associative, cognitive, and situative learning theories, including engagement and pedagogic elements with a focus upon feedback and flow principles (p.1).

Kiili et al. (2012) brings up an important point: that "the ultimate aim of game design is to create appealing experiences to players. Thus, games can be seen only as artifacts or a cultural form that arouses meaningful immersive experiences" (Kiili et al., 2012, p.78). Kiili et al. (2012) also argue that "The four basic elements that comprise every game are: mechanics, story, aesthetics and technology" and that all of these are essential with equal importance (Kiili et al., 2012, p. 79). Currently, MAEGUS is missing parts of the mechanics, story, and aesthetic portions. By applying the Flow framework, it can drive the user to a state of complete absorption in the MAEGUS simulation, which will lead to the optimal experience. Kiili et al. (2012) continues to comment that in this optimal experience the game becomes "an activity that produces such experiences so pleasant that the person may be willing to do something for its own sake, without being concerned with what he will get out of his action" (Kiili et al., 2012, p. 81).

The elements of flow can be separated into three categories: Flow antecedents, flow state and flow consequences (Kiili et al., 2012, p. 81). The flow antecedents are aspects that add to the flow state and focuses on providing a main goal with sub goals at appropriate pacing in order to create a sense of success. Kiili et al. argue that "If the goals seem too challenging, the probability of experiencing flow is low. Furthermore, the goals should be related to the learning objectives of the game. If the learning objectives are discrete from gameplay the game may fail to produce educationally effective experiences" (Kiili et al., 2012, p. 81).

The next aspect of Flow is flow state which focuses on the characteristics of the player during game-play such as concentration, time distortion, rewarding experience, and loss of self-consciousness. This element describes how a person becomes completely focused on the activity and is able to forget all unpleasant things. This happens because flow inducing activities require complete concentration of attention to the task at hand and no cognitive recourses are left for irrelevant information (Kiili et al., 2012).

Flow consequences is the final aspect of the flow framework that focuses on the end result of playing the game such as learning and showing exploratory behavior. This flow framework presents the design principles for " developing engaging game elements that take account of associative, cognitive and situative learning approaches" and can be used to greatly improve the design approach for MAEGUS's interface (Kiili et al., 2012, p. 89).

2.8 Visualization Frameworks of Energy Data

This section focuses on extracting relevant information from existing implementations of information visualization on energy data. These case studies range from home energy services to fuel consumption simulations. Although the MAEGUS simulation uses different technologies, these case studies offer insight into their design choices and design flow for visualization of energy data.

2.8.1 Energy Visualization Service in Home Network System

Watanabe, Nakamura & Matsumoto (2013) published a paper in IEEE that presents *Personalized Energy Visualization Service (PEVS)*, which dynamically generates appropriate visualization for individuals based on preferences. In this implementation, Watanabe uses a questionnaire in a goal-oriented fashion from the view points of term, unit and scope to consider the appropriate graph for the user (Watanabe et al., 2013). This experimental evaluation was successful in showing unique personalized visualization for every subject (Watanabe et al., 2013).

The value of this paper comes from Watanabe's argument that "by describing data in visual representations like graphs, users can intuitively understand the reality of energy usage" (Watanabe et al., 2013, p. 530). Understanding energy generation and the energy usage within the MAEGUS game will be key to promoting decision making behavior. PEVS also offers insights into the benefits of the dynamic visualization of energy while pointing out that static visualization methods can lead to users losing interest or in extreme cases, can lead to users being unsatisfied with the experience (Watanabe et al., 2013, p. 530).

The proposed method for this study can be broken down into the three following steps: Data Selection, Purpose Selection and Energy Chart Generation. In Data Selection the user specifies what energy consumption data will be visualized. The choices are based on the three following perspectives : Term, Unit, and Scope. Once the user selects one of the three perspectives, the type and range of data is determined and the process moves onto Purpose Selection. In step two, Purpose Selection, a user requirement is extracted using the data specified in step one generating a set of possible purposes for the data. Energy Chart Generation is the final step which generates an appropriate graph chart based on data specified in step one and according to the purpose selected in step two. The resulting visualization is displayed in the form of a Bar Chart, Line Chart, or Pie Chart.

2.8.2 Integrated Electricity Consumption and Contextual Information Visualization

Improving home energy efficiency with E^2Home*: A Web-based application for integrated electricity consumption and contextual information visualization* presents Energy-Efficient Home (E^2Home), which is a Web-based application for interactive visualization of electricity consumption data and contextual information. In E^2Home energy data is visualized through SVG-based interactive time charts and maps on a Web page (Ghidini & Das, 2012). Users can then explore them using brush-and-linking and panning and zooming to acquire actionable information. This study's contribution focuses on a system that uses contextual information, such as location and is fused with energy consumption data into a multidimensional data stream (Ghidini & Das, 2012, p. 471).

The E^2Home consists of the following processes: data collection, storage, fusion, and visualization (Ghidini & Das, 2012). The data collection portion downloads a CSV file with energy data and then uploads to the Couch DB database for storage. The next step is Data Fusion which uses two data streams with a defined view and a list function. The view function takes data points from the Map part of the MapReduce function and organizes them by timestamp while the list function reads the ordered data points into time slots and then computes the energy consumption. The final output data point sends out a joint data stream combining the two visual methods (Ghidini & Das, 2012, p. 472). Once the data is fused, the data can be visualized through the two following charts: a focus and context timeline for power consumption, and a map for the corresponding user location (Ghidini & Das, 2012, p. 472).

2.8.3 Visualization for Sustainable Living

Chasing the Negawatt: Visualization for Sustainable Living is a paper focused on finding ways that information visualization can contribute to the goal of helping users understand energy use without being technology experts, electrical engineers or control room operators (Bartram, Rodgers & Muise, 2010). The interests of this research are in line with the interests of designing a user interface with incorporation of appropriate visualization techniques to increase energy literacy in a serious game. Bartram et al. argue that "the challenge is to understand not only what kinds of visualizations are most effective but also where and how they fit into a larger information system to help residents make informed decisions " (Bartram et al., 2010, p. 8).

The paper begins by establishing the idea that until recently, energy visualization tended to fall in one of the two following categories (Bartram et al., 2010) :

1) Highly technical displays familiar to building engineers for tuning building performance or

2) Simplified displays of aggregated energy consumption over time usable by nonexperts (and familiar from the monthly electric bill).

(p. 8).

Bartram continues to state that "the combination of these tools can result in a confusing array of unconnected devices and information tools that require the resident to access, manage and integrate a confusing stream of information. " (Bartram et al., 2010, p.9).

One technology Bartram et al. brings up is the Energy Dashboard being an example of a common application of energy visualization (Bartram et al., 2010). These systems provide sophisticated displays and tools that support search analysis and some prediction of energy use (Bartram et al., 2010). Energy Dashboards offer core aspects that are essential to providing an informed analytical understanding of energy use in the MAEGUS simulation (Bartram et al., 2010).

Bartram ends the paper by pointing out "that the best way to address these issues is to take a broader systems-design perspective, opening the boundaries of what’s traditionally considered visualization. This is a fertile research area" (Bartram et al., 2010, p. 14).

2.8.4 Visualization Framework for Simulating Fuel Consumption Through Serious Games

In this study the authors focus on developing a visual traffic simulation framework with analyses of gas consumption and traffic flow (Sarlo, Foster & Wachowiak, 2012). This simulation is in the form of an agent based serious game containing visualization of virtual traffic generated pseudo-randomly with parameters to reflect real traffic patterns (Sarlo et al., 2012). The visualizations are represented in both two dimensions and three dimensions. The two dimensional aspect is represented as a color coded visualization of roads and cars simulated with traffic data. The three dimensional portion presents elevations for the user to make informed decisions on what is the better or faster road to take given the knowledge that hills or valleys present more or less weight. This paper is one example of many in the field of visualizing data in serious games for educational purposes. Sarlo et al. (2012) argue that the need to visualize the simulation comes from the difficulty of gaining insights from mathematical analyses alone.

2.9 Conclusion

The MAEGUS simulation is in need of a user interface that can effectively present information through multiple dynamic datasets simultaneously. This literature review creates a base of knowledge for designing such an interface through examples of design and visualization frameworks of energy data. The research details the explanation of methods for developing and evaluating this system in the next chapter.

CHAPTER 3. METHODOLOGY

This chapter defines the design and evaluation choices for this research study. The chapter game interface development, gameplay functions, information visualization, and evaluation methodology. The research methodology outlines the approach to the research in terms of sample and data collection. The game interface development section explains the considerations for the technical design of the game. The gameplay functions will overview how the subject will interact with the simulation. The information visualization portion explains what components will be visualized. The evaluation methodology covers the usability test at the end of the development. A usability test was chosen to document problems with the current implementation as well as to document overarching themes for developers to consider when developing similar systems. Other interesting phenomenon from observation or what participants say will also be documented.

3.1 Game Interface Development

The development of the user interface broke down into two major components: the heads up display and the game environment. The heads up display consisted of the user's primary tools for purchasing, upgrading, and placing sustainable energy technologies on the game environment as well as data visualization components that present the user with wattage, current resources, and other variables that help the user make strategic game decisions. The heads up display also provided information on each specific technology and also the controls to end each turn.

The game environment focused on visual feedback for the player on how decisions will and are affecting the player. Maps and textures communicated optimal areas to place wind turbines or solar panels as well as areas where the subject cannot build.

Decisions made through the heads up display will affect the game environment and vice versa. Currently MAEGUS uses a grid system on the game environment aspect. Visual feedbacks would be designed keeping in mind that the user interacts with a hexagon grid system. Existing data visualization techniques, presented in chapter two, was used in both the heads up display and game environment.

3.2 Gameplay Functions

The MAEGUS game used a turn based approach to game play, which was played on a hexagonal grid. Each grid marks an area where the subject could potentially build a wind turbine or solar panel. The subject could select creation of or upgrades for the wind turbine or solar panel through the provided heads up display. Players must effectively manage their energy generation to generate as much energy as he or she can within a limited amount of turns. While generating as much energy he or she can is the long term goal, short term or smaller goals have been implemented based on the research in designing educational games and game flow, talked about in chapter 2. These short term goals are energy goals that will increase funds and increase building space. Through the game the player will face the following limitations:

- **Funds:** A specific amount of funds is generated per turn with an extra amount based off city level and how well the wind and solar technologies are generating energy. All technologies and upgrades are based off these funds which limit how much the player can build.
- **Building space:** The player starts out with limited access to the map for building and is further limited by the environment as well as the technologies themselves which take up space.
- Varying levels of wind and solar concentration.
- Turns

To achieve these goals players must decide where to place the correct renewable energy technologies and when to build or upgrade the renewable energy technologies as well as decide between whether their choices benefit them in their long term goals or short term goals.

3.3 Information Visualization

The MAEGUS simulation incorporated a combination of heat maps, charts, and diagrams in the interface. These information visualization techniques were designed to visualize the following components to assist the user with decision making:

1) Variables that control wind turbine energy generation:

   a) Air density- because elevation is not a component of the game, the air density was standardized.

   b) Wind speed

   c) Power coefficient of the generator

   d) Length of blades

   e) Wind direction can deviate up to 90 degrees on either side before loss in energy generation. There were two main reasons that this was not visualized. The first reason was that wind direction was not something that affected the wind data model and the second was that the game play element of having to turn the turbines or having automatic turning turbines did not add any additional content to the study as shown in a pre-study on an earlier prototype of the game (Nataraja & Whittinghill, 2013).

2) Variables that control solar array energy generation:

   a) Solar density

   b) Material of solar array

   c) Tilt- Because the position of the sun was not a feature that added game play content, tilt was not appropriate to be visualized.

   d) Surface area of solar array

3) Global energy generation from all sustainable energy sources

4) Wind energy and solar energy output based on base turbine/solar array formulas.
5) Terrain information
6) Buildable and unbuildable hexes
7) Individual hex data

Visualization techniques were used in both the heads up display as well as the game environment. To assist with the decision making process the user should be informed on how their decisions could affect achieving their goals; this was done by providing the subject with graphs that predict energy generation over time with their current resources, wind turbines and solar arrays, against the changing variables for sustainable energy generation. The visualizations were designed around the guidelines presented in Chapter Two.

3.4 Wind and Solar Data

Once the variables of the game were determined it was important to either simulate or find data. The data model for MAEGUS was decided based on real data from the National Renewable Energy Laboratory (NREL) web page and a model inspired from Wilks and Wilby's notes on stocchastic models in *The weather generation game: a review of stochastic weather models* (NREL) (Wilks & Wilby, 1999). Ten years of wind data from various station data around the state of Indiana were used to create this model. The data was then randomized among sixteen regions that would later be applied to an eight by eight block of hexes. The solar data was created based on a range of solar concentration presented from NREL. Each region was assigned a solar concentration based on the range and then each hex within each region had a range of one above and one below the assigned number.

3.5 Implemented Game (Visualizations and Tools)

This section of the methodology shows the final implementation of the serious game with explanations on its final features and screenshots.

Figure 3.1 Intro

Figure 3.1 illustrates the opening for the player. The player is introduced to a guide called The Sage and the narrative for the game. Dickey argues that the inclusion of a narrative to game design can further engage the user and improve the overall experience of the game (Dickey, 2006). The brief introduces the player to the overall goal, generating as much energy as you can through wind and solar technologies, and the limitation of 20 turns.

Figure 3.2 Interface

Figure 3.2 shows all the visualizations and tools the player can interact with. Designs for the borders in the heads up display were designed by Tammy Trieu. The following is a list of implemented visualizations and interfaces with destructions of functionality.

3.5.1 Icons

Figure 3.3 Icons

Six icons and some visuals for controls were designed for the purposes of this study. The icons has a minimalistic approach to the design as well as some associated technical factors on layering the texture across the visualization. This legend appeared when the user clicked the "i" icon on the map visualization.

3.5.2 Map Visualization

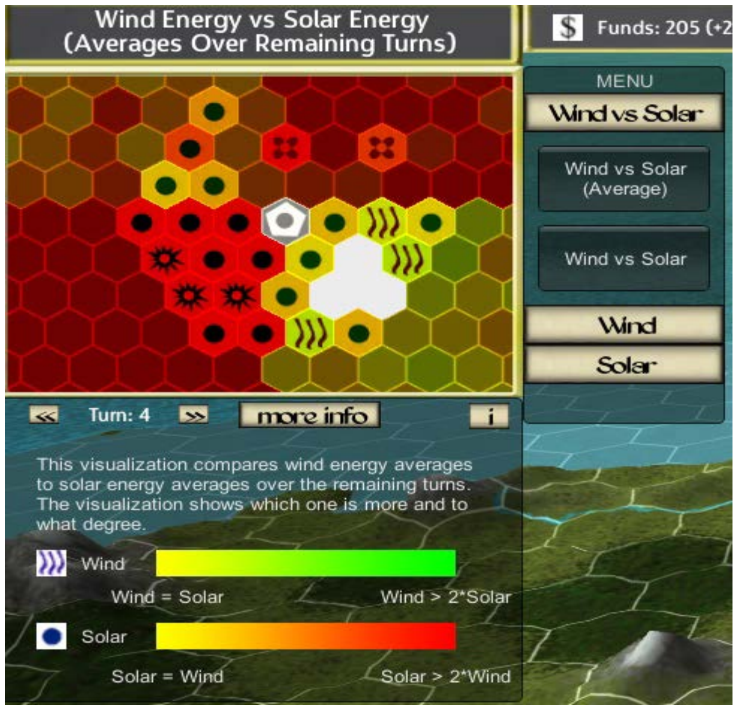

Figure 3.4 Map Visualization

Map Visualization: This visualization was chosen based off the concepts of overview and heat maps. The purpose of the visualization is to offer an overview of important energy information as well as providing a forecast of overall energy information that will offer insight on long term goals. This visualization includes the following features:

- **Visualization:** This visualization was based off a heat map as described in Data *Visualization- a Successful Design Process* and uses a color scheme with decreasing or increasing saturation or increasing light to create the sense of data magnitude ranking. This allows for rapid pattern matching to detect the order of hierarchy (Kirk, 2012, p.147). This visualization also uses icons to provide support on other game factors such as buildable or unbuildable space and whether wind is better than solar and vice versa. The following seven maps use this visualization: wind vs. solar (averages), wind vs. solar, wind energy (averages), wind energy, wind speed, solar energy, and solar concentration. These represented energy generation from base turbines and base solar arrays. Averages were defined in the title and the visualization description as average of the hex over the remaining turns. The user can interact with this visualization by clicking the map and using the "wasd" keys to pan as well as using the mouse to scroll. The visualization starts out zoomed out.

- **More info:** A panel that describes the current map as well as providing a legend for the current visualization.
- **Turns buttons:** These buttons allow the player to filter through the turns to forecast energy concentrations.
- **Side menu:** This collapsing menu hosts the different map visualizations categorized as wind vs. solar, wind, and solar.
- **Title:** At the top of the map visualization next to the resources bar it displays the full title of the visualization.

3.5.3 Resources and Energy Bar

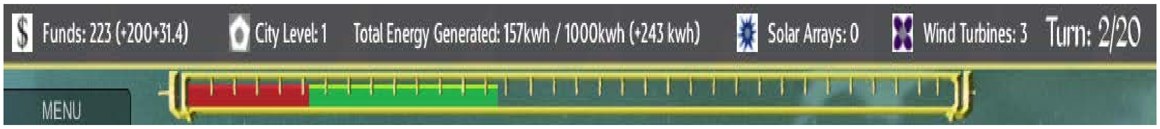

Figure 3.5 Resources and Energy Bar

Resources Bar: This is where the user found all the information about their current status in the game. This includes city level, funds, energy produced, number of wind turbines, number of solar panels, and turns remaining. At the top right this bar hosts the menu button which brings up the high scores, and buttons to quit the game. Changes in energy generation and funs are also displayed.

Energy Bar: Right below the resources bar is the energy bar which visualized the player's progress through each energy goal. Two bars are visualized through the energy bar. The first bar starting on the left represents the total energy the player has gained. The second bar, which starts at the end of the first bar, represents how much the player will be gaining once this turn is passed.

3.5.4 Tips

Figure 3.6 Tips

Tips: To the right of the energy bar, this offered words of wisdom from the sage about the game and advice on specific game play elements. This was designed by Kavin Nataraja. Art work designed by James He.

3.5.5 Minimap

Figure 3.7 Minimap

Minimap: Below the tips showed an over view of the map which can allow the player to pan and zoom just to have a second visual of the map. This was put in place to help the player with positioning when the map got too cluttered. Right above the minimap was the next turn button which is standard in the bottom right side of the screen for turn based games.

3.5.6 City Interface

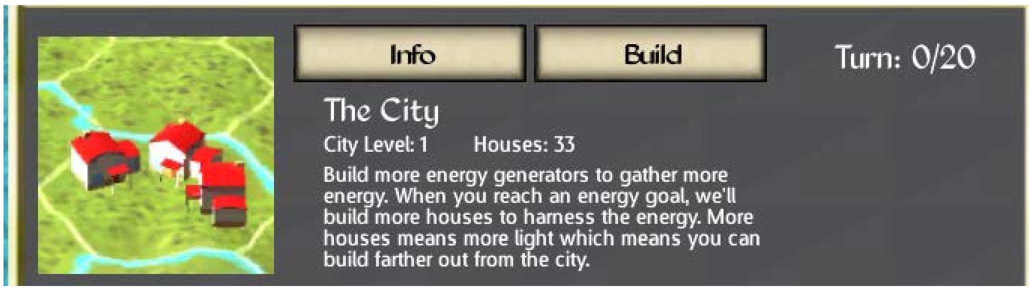

Figure 3.8 City Interface

City Interface: To the left of the minimap was the main interface for reading information on selected object, building, and upgrading based on what was selected. An image of the city would change in this interface as the city levels up. This interface would provide the costs associated with building or upgrading each technology and how your funds are affected in the process.

3.5.7 Hex Comparison

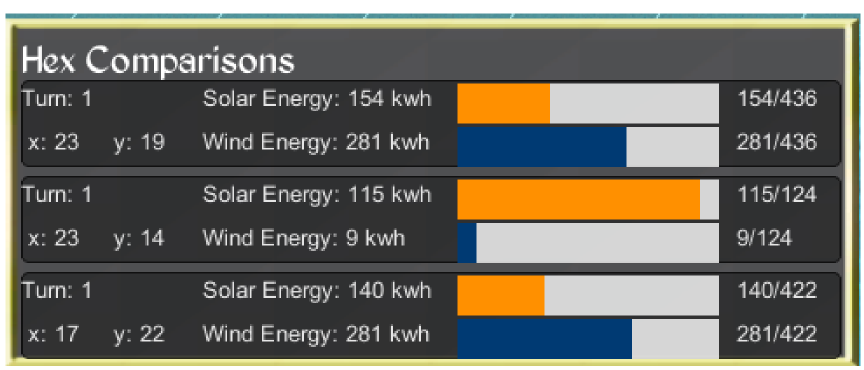

Figure 3.9 Hex Comparison

Hex Comparison: This interface allows the user to store up to three hex's information. The information stored includes the location as well as the wind and solar concentrations on that hex visualized as a horizontal bar. This was implemented so that the user could more easily compare hex information. To use this interface the user can click any hex and it will store the value into this interface cycling old data out and new data in.

3.5.8 Hover Display

Figure 3.10 Hover Display

Hover Display: This display shows up when the user hovers over a hex and disappears when the user hovers over any of the heads upheads up display interfaces. This interface brings a variety of valuable information to the user about a specific hex. When hovering over an empty hex the hover display shows the location, the terrain, whether the hex can be built on, solar and wind concentrations, the wind and solar equations, and a bar graph of the energy concentration of the hex based off base turbine and solar array contributions. The display changes slightly when hovering or clicking a specific wind turbine or solar array, where it will only display information about the energy type that powers the specific technology. Originally this was designed in the bottom left corner of the heads upheads up display, but was changed to be more interactive in the center of the screen as the player interacted with the hexes.

Figure 3.11 Game Map

Figure 3.11 shows some the game in action with the solar panels and wind turbines. The game map comprises of the following four primary objects:

3.5.9 Hex Grid

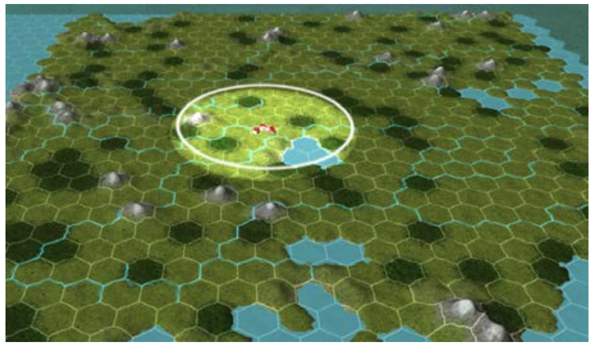

Figure 3.12 Hex Grid

Hex Grid: This is the entire game environment as 3d meshes using a unity asset called HexTech. Various types of terrain are represented on this grid such as plains, hills, mountains, lakes, and rivers. Each hex has its own terrain which also affects buildable space. When the user hovered over these build spaces the hex will highlight in red and when the user hovered over a buildable area the hex will turn white. Bigger hover visualizations will appear on top of the different objects on the hex grid to represent that it is selectable.

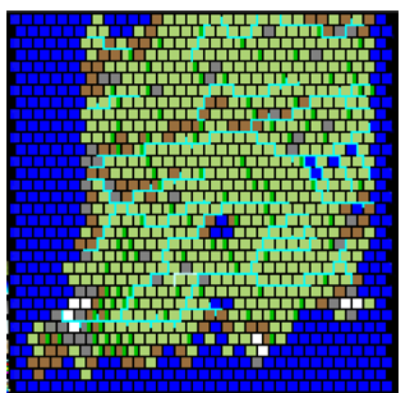

Figure 3.13 Hex Generation

The terrain is generated using a unity asset called HexTech using a pixel map. The figure above shows the pixel map that was used for the MAEGUS interface which is based off the state of Indiana. The shape was chosen because all the data models are based off Indiana data. In this case the surrounding area is covered by water due to limitations created by HexTech while remaining aesthetically pleasing. A compromise of the ideal design was made to keep the look consistent. At the beginning of the game a shadow is overlaid across the map with only a small lit area. As the player levels up the city and generates more energy the shadows are lifted and the lit area expands.

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3.5.10 Models

Figure 3.14 City Models

City Model: the city represented on a small hex is designed and modeled by William Huynh. These models will evolve as the city level increases adding in additional building models and becoming more and more modern.

Figure 3.15 Wind Turbine

Wind Turbine: the wind turbine was designed by William Huynh. The wind turbine models represent a wind farm with its bordering hexes replaced with posts. These posts communicate to the player that these hexes are unavailable to avoid the wake effect. Other aspects are also communicated to the player such as varying wind speeds and visible changes after upgrading blade length or the generator. The turbine will spin faster or slower based on the wind speed of the turn.

Figure 3.16 Solar Array

Solar Array: The solar array model was designed by William Huynh. This model only takes a single hex so the player can in theory build more solar arrays than wind turbines across the map. The affects of upgrades are also visible through changes in the color of the tiles or increasing the size of the array with more panels.

Figure 3.17 High Scores

Figure 3.17 shows the high score table that appears once all turns are over and concludes the game. If the user achieves a high score he or she can place a three character name on the leader boards. The amount of energy generated, the houses powered, the amount of wind turbines built, and the amounts of solar arrays built are also saved on the boards. This is to add a competitive nature to the game for replay-ability as well as some insight into how other players may have achieved such high scores. This was designed by Kavin Nataraja.

3.6 Game Architecture

This section describes a brief of the MAEGUS game architecture from a programming perspective. The base of the MAEGUS interface was developed by Colossus Entertainment, a group formed for a capstone course in computer graphics technology at Purdue University, using a unity asset called HexTech. The provided base provides the creation of a hex mesh with limited terrain generation. This hex mesh provides functions for tracking specific hexes the player interacts with in accordance to mouse position. With the understanding on how players can interact with specific hexes, the game can be built. A hex mesh was used instead of individual hex objects for better dynamic environment creation with less performance issues.

Although several classes and script files were used, this section aims to provide a high level look on how the game was designed. The following figure provides a flow chart for implementation of the design.

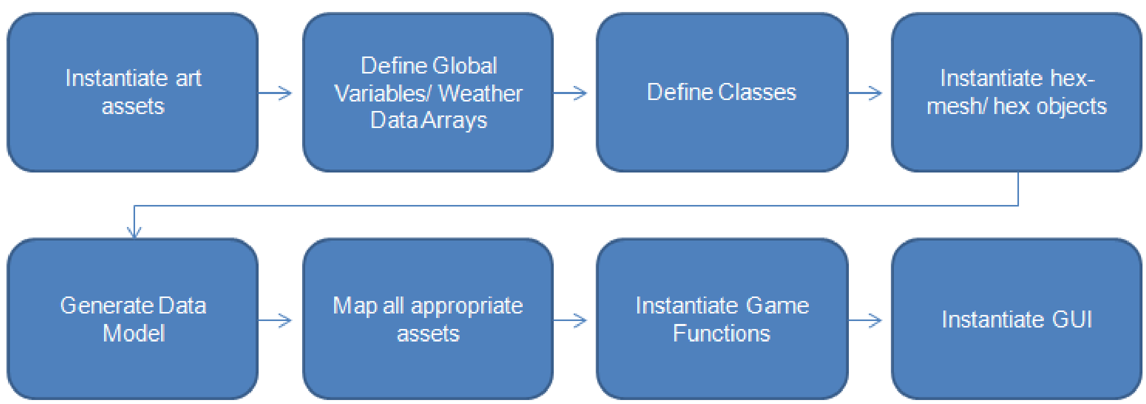

Figure 3.18 Game Architecture

The first step in the M.A.E.G.U.S serious game is to instantiate the art assets for the graphical user interface or GUI and any other objects used in the game. This is a standard practice as manipulation of these assets, because there is less overhead if they are preloaded. The next step defines all global variables of the system as well as importing the weather data for programming use. Once the variables are defined the classes used for storing hex data and calculating energy are created. These parts define the initial setup for the system.

The meat of the programming is defined within the three following functions: Start, Update, and OnGUI.

- **The Start function:** This creates the base for the game which instantiates all the important variables in the correct spots. In this section the data model is created using the weather data and distributed across the hexes. The hex mesh is then created with the assigned materials generated from a pixel map. The map visualization's hexes are defined as hex objects, different from the hex mesh, due to technical obstacles and are generated outside the main camera's view.
- **The Update function:** The update function is a function that is called once all parts of the game are instantiated and is called when any system component needs to be updated. This function handles all functionality for interacting with the game outside the GUI. The Update function incorporates how the player interacts with the system and updates the appropriate assets to provide visual feedback on how the system is changing outside of the GUI. These changes could be how colors and textures change, or displays of visual effects when the player interacts with components of the game.
- **The OnGUI function:** The majority of the game's tools and interface is described in this section. This function insures that the two dimensional interface is produced on top the game. Assets for the heads up display

are created within this function and other camera views for the map visualization and minimap are layered on top of the GUI. Both the functionality and appearance of the GUI system is defined here.

After the start function is run the system alters between the Update and OnGUI functions as the player interacts with the serious game. The separation of these tasks insures a level of organization for changes to the system or expansion of the system.

3.7 Evaluation Methodology

The MAEGUS interface was improved by applying existing data visualization techniques and tested through volunteer participants with the goals to find usability issues and understand how participants used visualizations to operate the game. There were five participants between eighteen and thirty five years of age within Purdue University with mixed backgrounds and mixed genders who are familiar with a keyboard mouse interface and were not color impaired. The number of participants was chosen for the two following reasons:

1. **Three to Five user rule:** In the paper *Heuristic evaluation of user interfaces*, Nielsen and Molich found that 80% of their UX problems could be detected with four to five participants (Nielsen & Molich, 1990). This assumes the two following conditions so it may not always be applicable:

- Each participant has a constant detection rate, p
- Each UX problem is equally likely to be found in testing

(Hartson & Pyla, 2012)

2. **Time:** At the end of the day time is a major decision maker. Due to the time constraints only five participants were chosen.

A usability test was conducted, modeled around the paper Usability *Testing for Educational Computer Game Using Observation Method (2010)* with the Think Aloud protocol techniques proposed in *The UX Book (2012)*.This is described more in detail further in the chapter. The test should take no more than one hour per participant. Before the test could begin, a consent form needs to be drafted, an IRB application processed, participants recruited, and test materials prepared. The IRB approval insures that your study does not harm the participant and also that the researcher takes measures to insure confidentiality.

3.7.1 Test Materials

The following materials were prepared before running the usability test.

1) A facilitator will handle the usability test.
2) A quiet well lit room
3) A quiet testing environment that includes the following:
   - **Computer:** Includes fully functional unity simulation, video camera, and microphone.
   - **Sound devices:** There will be sound and feedback to the user while interacting with the game.

- **Screen recording software (Morae):** software used to record how the user interacts with the software, their mouse position, audio, and video of the participant.

4) IRB approved consent form (see Appendix A).

5) A semi structured task list for the facilitator asking background questions, a few identification tasks, and a post interview.

3.7.2 Conducting the Usability Test

The usability test was conducted in the quiet test environment with the facilitator. A consent form was provided to the participant (see Appendix A). Once the consent form was signed the facilitator reviews the semi structured tasks and questions (see Appendix B) stating that all comments would scrutinize the system not the participant. Morae, the video, screen and audio recorder was turned on and the testing began. The participant was screened for demographics such as age, background, experience with information visualization, experience with turn based games, experience in computer simulations, and basic understanding of sustainable energy technologies.

At this point the participant was briefed about the gameplay elements and introduced to the system. The usability testing was broken up into two parts. The first was based on an information finding and identification task of the following four visualization tools: map visualization, hover display, hex comparison, and minimap. This was to offer some context on the user's understandability of the visualizations and to have some insight into what the user thinks before the think aloud protocol, and what the user thinks afterwards.

The second half of the usability test was a think aloud protocol where the participant played through all twenty turns of the serious game while talking about their decisions, frustrations, suggestions, or thoughts. Originally used as a psychological research method by Ericsson and Simon. Nielsen argues that "Thinking aloud may be the single most valuable usability engineering method" (Nielsen, 1993, p.195). Another claim by Nielsen is that "the strength of the thinking- aloud method is to show what the users are doing and why they are doing it while they are doing it in order to avoid later rationalizations" (Nielson, 1993, p.195). In a think- aloud study a player verbally expresses thoughts, feelings and actions experienced during game play. The think aloud method is one of the most widely used and effective ways to produce actionable results for game designers according to the paper *Methods for Game User Research - Studying Player Behavior to Enhance Game Design* (Desurvire & El-Nasr, 2013).

There were some guidelines to follow according to Nielsen and *The UX Book* when using the think aloud study. The first step was to explain to the participant that he or she should be thinking aloud when they are playing in the game. The facilitator should act like a mirror for the participant only stepping in when necessary. The facilitator should also keep watch of what the participant is doing and ask questions like "what are you thinking now?" as well as remind the participant to think aloud or to speak up if they are frustrated. Although not done on this study, other think aloud studies may have a separate task to get the participant to practice thinking aloud. A few pilot runs of the study showed that participants generally take about an hour to complete the study so there was no room for practice time for the participant. The facilitator should also keep in mind, as the expert, to be careful when a participant gives a false impression or of giving too much weight to the user's own "theories" for what caused the trouble or what would help (Nielsen, 1993).

There were a few downsides to the think aloud approach. For starters, in games especially, it is difficult to think aloud when playing a game in real time and make decisions on the fly. Luckily the think aloud method avoids this difficulty for MAEGUS by being a turn based game with unlimited time between each turn. The main disadvantage of the think aloud method is that it does not lend itself very well to most types of performance measurement (Nielsen, 1993, p. 195); this was one of the down sides of the study for not being able to conclude that visualizations helped players obtain a better score.

Both transcripts and observational data was collected to be analyzed for a better understanding about the usability. The user finally participated in a post interview on what they enjoyed, or did not enjoy in the game and if the information visualizations communicated everything clearly or helped in the decision making process.

3.8 Conclusion

This chapter provides an overview of what components of the interface were developed and the usability testing for the MAEGUS game interface. Areas covered by this chapter include interface development, gameplay functions, information visualization, implemented gameplay, and testing methodology. The next chapter covers the results of the usability test as qualitative data and analysis process.

CHAPTER 4. RESULTS

This chapter presents the analysis process based off a thematic analysis approach to find usability problems and over arching themes for problems. This chapter presents the results according to the original research question: how do students use a series of information visualizations to operate a multi-variate game-based simulation and what are the associated usability issues?

4.1 Data Analysis Process

Once the usability test concluded there was a lot of raw data that needed to be documented, sorted, and analyzed. The first part of this analysis process is to review through each video and transcribe as well as take notes on interesting observations. The notes taken during the usability test should assist the researcher in identifying usability issues. For this study's usability test videos, the transcription was documented in the form of a table with time stamps of when the participant or the researcher spoke as well as what the participant or researcher said. To protect the participant's confidentiality, each participant was assigned an alias.

4.2 Thematic Analysis

The goal of thematic analysis is to identify, analyze, and report patterns within data. The usability test uses a thematic analysis which followed the following process:

1. Familiarizing yourself with the data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes
5. Defining and naming themes
6. Producing report

(Braun & Clarke, 2006).

Once the initial codes are generated each

Overarching themes are then discussed; in this case, themes focus primarily on grouping trending problems, but will still show any other interesting trends in data. Interpretation and discussion of these trends will take place in chapter five.

4.3 Coding

After everything is transcribed it is time for the coding process. The process for MAEGUS used a bottom up approach starting with an open coding approach(Berg & Lune, 2012). After using open coding on a few transcriptions the a trend emerged and was documented to make future coding more consistent to the format and old codes were re-coded to fit the new more organized structure. A code book was created (see Appendix C) from the findings and discusses more in the results section. Specific problems were identified for each participant and organized based on the codes. The codes were separated into types just for better organization. There was an interface code, a player code, and a statement code. Each statement code had a corresponding interface code and player code to identify the correct location. The interface code attached the specific interface the user was talking about, and the player code suggests either what the player was thinking , feeling, or suggesting.

4.4 Participant Backgrounds

Asking about the participant's background gives some context to how the participant is acting. The following tables present the backgrounds for each participant. Some of these questions also used a seven point Likert scale which checked how comfortable or how knowledgeable the participant is at a particular subject. None of the participants were colorblind.

Table 4.1 Age

#	Age	Year	Gender
1	20	senior	Male
2	19	freshman	Female
3	20	sophomore	Male
4	22	senior	Male
5	18	freshman	Male

The gaming background question aims to ask the participant about their familiarity with pc gaming or turn based gaming. A seven point Likert scale is used for measuring experience; one being not very experienced or seven being very experienced.

Table 4.2 Gaming Background

#	Participant Response	Research Note
Participant 1	4 . "I don't consider myself a threat enough to do real damage. I don't consider myself a threat enough to do real damage"	• Very confident with pc gaming • played various types of turn based games similar to MAEGUS like civilization and various turn based strategy games.
Participant 2	3 or 4 " Pc gaming no so much I played much more of it as a kid. I played some of the first civilizations like 6-7-8 years old, umm runescape as I was younger. turn based now if it is based on console, if they have that"	• somewhat familiar with gaming but not much experience in turn based.
Participant 3	6.5 "umm the only reason is because I have testing things similar to this like other games in highschool. they tried to make it fun and interesting. it was a math game they called it math cat or something. that was something I tested out. I played civ and tycoon as well so I could relate."	• Played very similar games as well as some of the games that inspired MAEGUS. Pretty experienced in pc gaming

Table 2 Gaming Background Continued

Participant 4	7 " Pc gaming Id rank myself a 7 cus I almost exclusively play PC games now. Turn based game I would probably say 6, like I have civ and I've put a ton of hours into it, but I wouldn't say I'm good at it. "	• Very experienced at pc gaming, also played turn based games.
Participant 5	6 " So PC games like Call of Duty and need for speed. Also, league of legends and fps games, shooting games. " but when asked about turn based pc games " Maybe when I was little I played those kinds of games but Now I am not so interested in those types of games."	• Very familiar with gaming, but not so much for turn based games

This question asks the participants how comfortable do they feel using heat maps, graphs, charts, and other visualizations. One is not very comfortable to Seven which is very comfortable.

Table 4.3 Using Visualizations

#	Participant Response	Researcher Note
Participant 1	5. "Not that bad science used to be my thing"	• Fairly confident with reading visualizations
Participant 2	5 " Pretty good as long as it has things properly described. "	• Should be ok with working with visualizations as long as he/she can read more about it.
Participant 3	5 " Maybe not too comfortable. "	• perhaps an inflated number, participant is not that familiar with visualizations.
Participant 4	5-7 " Heat maps? 5. The only heat maps I've used are like halo depth maps or league of legend depth maps but graphs and charts I can read at like 6 "	• comfortable with generic charts, a little less for other kinds of visualizations such as heat maps.

Table 4.3 continued

Participant 5	5 "Hmm so like numbers, bar charts? Do I have to give a number?"	• somewhat comfortable

This question asks about how familiar the player understands sustainable technologies which may affect how they play the game.

Table 4.4 Familiarity with Sustainable Technologies

#	Participant Response	Researcher Notes
Participant 1	"Yeah, I've been going to green fest since 7 years ago with my parents"	• seems pretty confident understanding how sustainable technologies work.
Participant 2	"How much I remember? that may be different but I did take an engineering course in my senior year that focused on solar energy and wind turbines. More than the average American, but not so much that I am fluent in the technology."	• Better than the average person and took a course learning about energy technologies.
Participant 3	"I don't know the process but I just know that it simply comes from the wind for windturbines and solar for solar arrays.. hehehe"	• very basic understanding but not much experience or knowledge.
Participant 4	"Oh no I guess I sort of know what they do but I don't know so much about them."	• very basic understanding but not much experience or knowledge.
Participant 5	"I'd say maybe a little "	• not much experience or knowledge.

4.5 Participant Reports

After the transcriptions were coded a usability report per participant was created, see (Appendix D). Each report categorizes instances based off the code book , first using the player code and then followed up with the interface code and a corresponding statement. The structure of the report is in the form of a table with player codes on the left showing what they understand, feeling, or suggesting and the corresponding statement on the right. These reports were used to see better see trends between participants for categorizing usability issues and documenting any other interesting observations.

4.5.1 Game Reports

This section results reports the interesting player and game data observed through the think aloud protocol. Phenomenon such as player strategies and player assumptions are discussed as well as the overall impressions of the game. The emergence of this interesting data on how the player uses the visualizations may pave the way to polishing the visualizations and the game as a whole.

4.5.1.1 Player Strategies

How players evolved during testing of the game was very interesting as different types of strategies started emerging. All strategies still revolved around using visualizations to interpret data, but some players would primarily focus on short term goals where as others focused on long term goals. The following table shows the in game results of the players:

Table 4.5 Player Scores

Participant #	Energy	Wind Turbines	Solar Arrays	Use of Upgrades
1	64673	30	9	moderate
2	84102	8	22	moderate
3	77374	6	15	high
4	74750	6	10	high
5	64570	5	5	high

From the observational data, the players who quickly realized through the visualizations to use a combination of short term goal decisions as well as a few long term decisions they could gain the highest energy outputs. Players who over produced technologies did not necessarily do better than players who built only a few technologies if those few technologies are placed in optimal locations. Players who built more solar panels and upgraded solar panels received higher scores. Players primarily used a combination of the Wind vs. Solar Averages map and the hover display to make their decisions. Other factors such as funds, building vs. upgrading, and remaining space also played a part in this decision making.

4.5.1.2 User Assumptions

Another interesting occurrence was based off a usability issue of not being able to see how much an upgrade for a technology meant. Although a cost was associated and the data was presented in the hover display, the user began to either make assumptions of use he use other interfaces such as tips or the energy bar to make assumptions. The player used other visualizations and tools to make assumptions.

4.5.1.3 Game Feel

The game as a whole was found to be fun by the players averaging a 5.8 out of 7; 1 being not fun or interesting and 7 being very fun. The length of the game was originally determined from the limited data model for the study, but through testing it seemed that it was an appropriate amount for the length of the tests. With each level increase of the city , the complexity of the game increased, and so did the length of each turn. It was important to determine a cutoff point before the complexity overwhelms the player especially in a game with limited gameplay interactions. In this case twenty turns worked splendidly.

4.6 Usability Issues

This section presents the usability issues experienced by the participants categorized by severity levels. The following 0 to 4 rating scale was used by Nielsen for the severity of usability problems:

- 0 = I don't agree that this is a usability problem at all

- 1 = Cosmetic problem only: need not be fixed unless extra time is available on project
- 2 = Minor usability problem: fixing this should be given low priority
- 3 = Major usability problem: important to fix, so should be given high priority
- 4 = Usability catastrophe: imperative to fix this before product can be released

(Nielsen, 1995).

This study uses a slightly modified version of Nielsen's model for simplification purposes. This study will also use the severity levels of critical, moderate, and minor usability issues defined in the code book (see Appendix C) . Frequency was also a factor that affected which category these problems were placed in. Nielson's heuristic principles also helped the researcher further understand the cause of the usability issue (Nielsen, 1994). Each problem within each category is described with supporting comments and a solution is proposed.

4.6.1 Critical Problems

Upgrades: Players were unsure how much benfits upgrades provided or which upgrade was better. The players would use tips, the energy bar, or their own assumptions to try to gauge the potency of the upgrade. For several players they would upgrade their technologies even though you are unsure how much they are getting from it in return, because of personal preferences of having higher quality units.

Recommendations: Implement information about what percentage of the energy equation does the upgrade affect as well as attaching the numbers of the specific energy the player will receive for the upgrade. Make sure the hover display is also affected by this change.

Participant Comments:

" I can click these and now I can upgrade.. it does not tell me how much it upgrades. I assume these 2 are both equality beneficial to me. "

"I understand that upgrading will obviously make the turbines better but between blade length and wind efficiency I'm not sure what the difference is or equal"

Unnoticed Buttons: The buttons underneath the map visualization were very hard to spot or completely unnoticed. The buttons were too small, the more info on default was closed leading to confusion about the maps, and the side menu was too big distracting from the buttons below.

Recommendations: Apply a background to the buttons below the visualization while increasing the size of the buttons and decreasing the size of the side menu. Keep the more info tab open on start to draw more attention and the user's eye to the other features on the visualization.

Participant Comments:

"Oh right here I see. Yeah I guess I was just not paying attention about that. I was concentrating on the side menu over here. "

Unnoticed Controls/ Annoying Controls: The features of panning, and zooming where completely unapparent on the map visualization and minimap. Participants were also annoyed by the fact that they needed to click on the visualization to interact with it and some participants even got confused where to click to switch the controls over to the map visualization or minimap. This violates "visibility of system status" where the player is not getting enough feedback on what the system can do. This can also be described as an issue of affordance which describes how its properties allows the player to perform a certain action.

Recommendations: The map visualization should have some kind of visual to show that it can zoom and pan similar to Google maps. Also instead of clicking on the visualization to change the controls the player should be able to switch the controls simply by hovering over the visualization. Upon further observation and the discovery of the scalability issue it was apparent that the players only interacted with the map visualization only when the city level increased. In this case, the visualization should start zoomed in instead of zoomed out and automatically zoom out as the city expands.

Participant Comments:

" It wasn't apparent but what would make it more apparent is if..... and I would know where to find it if I needed it to."

" Maybe it would be better if you made like a little animation that showed it zooming in. it will automatically zoom in and zoom out, and a little text to tell that you can zoom in and zoom out with the mouse. "

"I wish I could just hover on it and it will automatically change the controls"

Unsure Wind vs. Solar Average: Participants were confused by name Wind vs. Solar Average, especially compared to Wind vs. Solar. This was a problem of "match between system and real world." Another problem was that the player would sometimes try to distinguish the difference without looking or reading the more info tabs. The participants would also ignore the title which included the full name of the visualization, but when they read the title or the more info they instantly understood the map.

Recommendations: A better name needs to be tested and changed in the side menu. The title needs to be more apparent and stand out. Having the more info tab open will also make things less confusing. The Wind vs. Solar visualization may not be needed as the hover display essentially covers the same information.

Participant Comments:

"I guess I do understand the constants. separate the wind and solar, that's really easy**,** but I guess when it gets to wind and solar average that throws me off a bit."

"Ahhh I see. mhmm yeah it should be like more clear like you can write wind vs solar current turn and this one is better for like all turns"

Confusing Icons: Some of the icons were a little confusing even though a legend was provided. This was another violation of "match between system and real world."

Recommendations: should be redesigned to more closely represent the actual object. Also, make the legend for the icons visible at all time for reference with the ability to toggle off for more experienced players.

Participant Comments:

"Umm hmm I understand the solar array is that sun. Hmmm I'm not sure I like. I also know that that is for wind turbines, hmm they're not close enough, I don't know if they're close enough to what you see in game as a model. "

Confusion with Energy Bar: There were several parts that confused participants with the energy bar. The first is an immediate association of the colors with other visualizations. This is a violation of "consistency and standards." Other confusions raised when players did not understand why where were two different bars , one for showing the total energy generated and one for showing how much he or she will be generating.

Recommendations: Make sure that the energy bar uses different colors as not to confuse the players for consistency and standards. Attach more visualizations to represent the goals displayed by the energy bar such as energy generated, total energy, next city level goal. A toggle button can also be implemented to describe what happens when the goal is reached such as additional funds, new city model, and expanded buildable area.

Participant Comments:

"I don't know if I missed something there I know how much energy i am producing does the red mean how much energy I am using? "

" It feels like I am going towards a goal but the green might be longer than what it is showing. "

4.6.2 Moderate Problems

Game Map Uncertainty: There were some uncertainties surrounding the game map on how to expand the map. Some believed it was unclear where the starting point of the game was even with a lit vs. unlit area. There were also some minor confusions of buildable terrain.

Recommendations: Whether arrows pointing at the build area or a notification to the user. It was clear that the fog and lit area only gave partial affordance. Some of the terrain also should be reviewed for whether it visually communicates that you can or cannot build there. The terrain, hilled forest, is especially hard to tell from a regular forest.

Participant Comments:

"Can I only build in this circle over here? there is no way for me to expand my circle this point in time?"

"Maybe if there were little arrows showing that this is where you build. Tell the user you have to start here"

Lacking/Inconsistent Power User Tools: There were several inconsistencies or lacking functionality for power users. This violates "flexibility and efficiency of use". These issues consist of not being able to build or upgrade faster, not being able to flip through visualizations and back faster, hot keys to continually build or cancel commands. Interfaces with extra information should have a toggle for the extra information. These were generally recommended by the more experienced players. This was another indications that scalability was an issue.

Recommendations: Building sustainable technologies should allow the player to continue to build until the player cancels by clicking the cancel button or the hot key for canceling. The turn button in the map visualization should better accommodate returning to current turn. Some suggestions for this is to use a slider or text box to scale this better. The tips interface was called out twice for not being able to hide indicating that any extra information should be given a toggle property.

Participant Comments:

"That's something personal, but if I right click turn off build mode or something like that so if I right click I can cancel building or something like that."

" I was wondering if I could shift click to create multiple ones, but that is fine."

Problems with Hex Comparison: Although perceived to be useful at the beginning of the study by the participants, hex comparisons was not used much to assist the player. There are several explanations why this may be the case. These are some of the reasons why it may not have been popular or used, was that the hex comparison did not store enough data, the time when it is useful is only late in the game as participants can remember data quite easily, or the hex comparison did not show enough data on the marked locations.

Recommendations: This interface will require more play testing to understand how effective it is or if it is not very effective. The amount of stored data should be improved and should mark the game map where it was clicked on.

Participant Comments:

"its nice that I could get the information, but the way it sorts the information. if I click real fast the hexes get lost. it would be nice if there was a hover function that tells me which one was clicked"

"I don't pay much attention to the hex comparison after better understanding this graph. so I think this[map visualization] helps a lot more than this[hex comparisons]"

"This was nice but I didn't need it[hex comparison]"

Minimap Unused: The minimap was hardly used to assist the player.

Recommendations: The two options are to either remove it or to combine the map visualization with the minimap. Both options must consider how to reformat the next turn button to stay in the right position while removing the minimap as most participants, still liked the visual appeal of the minimap even though they didn't fully utilize it. This feature may be more useful if the map was bigger and the minimap had more of a direct control of the game map. For option two combining the minimap and the map visualization this is not possible due to technical restraints, but features of the minimap can be analyzed and incorporated into the map visualization. One example is hovering over a hex will display a glowing hex in the map visualization.

Participant Comments:

"Maybe these two are can combine.[points at top data vis]"

" and I think the minimap is just there for visual appeal "

"Uhh it was nice I like that it showed the space so it was nice to see where I'm at but I didn't know how to use it effectively..."

4.6.3 Minor Problems

Tiny Text: The text displayed in the popup were a little small causing players to move closer to the screen.

Recommendations: Increase the size of text in the boxes making sure other text in the system are not affected by this change.

Participant Comments:

"The text is a little tiny [looks closely at screen]"

Inconsistent Colors Between Map Visualization and Hover Display:

There are some inconsistencies in color, the map visualization used red and green, but a different color combination may have been better. Blue and orange created gradients of gray in the map visualization so the map visualization used red and green where as the hover display and hex comparison used blue and orange. Only one participant expressed his opinion on this.

Recommendations:

Try out alternative colors that still work with the theme of the game, but are more in line, consistent, and clear.

Participant Comments:

" I would have went with blue and orange but yeah that makes sense. blue and orange seems more in line with the other parts of the interface."

Turn 0 : The game started on turn 0 which was determined because arrays start at 0 and it was easier to keep track of on the technical side. On the player side however this caused confusion because of the violation," match between system and the real world ."

Recommendations: Add one to all displayed text that involve turns and subtract one to compensate for the technical change.

Participant Comments:

"Oh that is kinda weird it is turn 9 as the half way point isn't it turn 10 as the half way point? "

4.7 Scalability

After iterating through the observational data, reoccurring problems, and other reoccurring comments it became apparent to the researcher that scalability was not taken into account. Scalability was a theme that emerged and in this setting was defined as the interface or functionality will be usable without creating situations of frustration as the buildable area in the game map expands and the complexity of the game increases. The conclusion that scalability was an issue came from participants believing that interfaces lacked features that allowed the user to quickly repeat a task and observations that certain interfaces of the game were left unused until the game reached a certain size by which the participant generally regretted that they had not noticed it sooner. The following issues flagged this as an over arching theme:

- Map visualization: How the map visualization was being used and initiated didn't make sense if this game were to be scaled bigger. The Player primarily needed to zoom into the visualization to use it, so in this sense the scale of the visualization was not taken into account.
- Map visualization- forecasting: it was difficult to flip through the turns to see trends when using the map visualization. There was also no quick way to return to current turn.
- Lack of power user tools to speed up iteration: As the game scaled and the game area expanded the user needed to build more and upgrade more, but there was nothing implemented to make this faster. The user must click each build and upgrade individually.

This idea of scalability is an expanded version the heuristic principle "flexibility and ease of use" by adding flexibility of system expansion. Visualizations should expand or focus in accordance with the user's needs. Future developers should take scalability into consider when creating a system that uses information visualization.

4.8 Conclusion

This chapter presents the process from raw data to themes. Processes such as thematic analysis and coding are discussed. The results of each participant are documented in an organized manner and any interesting game data was reported. An over arching issue was found and usability problems found after coding were then categorized by severity with solutions recommended. The next chapter is about discussions, future work, and conclusion.

CHAPTER 5. DISCUSSION

The main goal of this study is to develop one possible solution for MAEGUS that incorporates visualizations and tools to assist the user in interpreting the raw data while still being a fun and interesting experience. Secondary goals are to see how students use these visualizations in their decision making process and also detect what are the usability issues associated with the current implementation. This chapter covers discussion of the implemented game, limiting factors, usability test, future work, and conclusion.

5.1 Game Discussion

Figure 5.1 Comparison

The figure above illustrates where the game was in the pilot study implemented by Colossus Entertainment on the left as compared to the current version of MAEGUS shown on the right (Nataraja & Whittinghill, 2013). From the pilot study the researcher found that the previous game play model was not sustainable and ultimately not fun. Because of this a new game model had to be implemented which incorporates new variables determined in Nataraja's study. The game then went back to the drawing board and required more research. The researcher in this study helped solidify a backbone for MAEGUS that would make use of data visualizations. Once the backbone was in place the visualizations were designed and developed. Specific designs are discussed in chapter three.

5.2 Limiting Factors

Several limitations impacted the development of an ideal design and execution . There were two major factors that limited the design of the study. One was the implementation of designing an intuitive game play that was not only fun, but also was focused on the purpose of promoting sustainable energy technologies as well as teaching about the specific variables that go into the generation of wind and solar energies. Once the game design was implemented the data must be modeled and distributed across the game appropriately based off game play. Only after these features have been implemented can the design of the visualizations and interface be determined, because determining the correct visualization is completely based on what information is needed to be conveyed to the player. This impacted the allowed time for the study and ultimately the ideal design.

Another major limiting factor was the unity system itself. The researcher faced many types of technical limitations based off the hextech asset in Unity.

Ideal designs on paper could not be implemented due to technical limitations created in the unity interface in relation to time. The time allowed for the study could not accommodate certain features within the ideal design so new solutions had to be implemented to compensate for the loss especially for key gameplay features that could affect the player's decision making.

Another smaller limitation was the lack of personnel on the development. MAEGUS was primarily developed by two researchers. Because there was very little assistance, the researchers had to design the game, design the assets of the game, and develop the game within a limited amount of time with limited resources.

5.3 Usability Test

The usability test found several issues that still needs to be addressed as well as some interesting qualitative data on player strategies and suggestions. The think aloud protocol and heuristic evaluation helped catch several bugs with the current implementation of the game, but more it is apparent that more iterations of usability testing and play testing are needed for a more polished game. The usability test also presented other questions of usability and user experience. one example is the balance of the game variables. From the results in player scores it already starts to show a trend that players who build more solar panels were getting higher scores, because there were only five participants we can't be sure if that is coincidence or a real problem with balance in the game. The potency of upgrades is another study in itself. Overall the usability study approach was a quick inexpensive way to find a lot of problems and overarching issues such as the scalability issue found in this study.

5.4 Future Work

Future researchers interested in MAEGUS have several avenues for future development. This thesis shows the design process of data visualizations within a serious game for a specific type of data model and specific game play model, but this can be expanded, so some possibilities for future work include looking into expanding the game as a whole, looking into the evolution of player strategy, and introducing other types of energy generating technologies into the game. Many other studies can emerge from using MAEGUS as a learning tool as one of the big opportunities missed in this thesis is studying if visualizations affect the player scores which could be done with two versions of the game. Any future researcher will also need to work on refining the interface to find and implement a better solution to deal with overall scalability issue.

5.5 Conclusion

This study presented one possible solution to use data visualizations to interpret raw data within a multivariate game based simulation to assist in the decision making process using pre existing data visualization techniques while still being fun and intuitive. This thesis presents the process of development from the ground up starting with finding the core variables in literature for sustainable technologies, developing data models, and finally presenting the appropriate visualizations to assist in game play. A think aloud usability test is conducted once development ended to find remaining usability issues and to observer how players user these visualizations to assist in their decision making for this serious game. The test was analyzed for any themes as well as any other interesting observed data. Through the analysis the idea of scalability became apparent as the source for several issues in the design and recommended to future developers creating similar systems to take this into consideration. Although this serious game still has a few things to flesh out, players enjoyed the game and the complexity was enough that players began to develop their own strategies using information from the data visualizations.

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APPENDICES

Appendix A. Consent Form

APPROVED
MAR 10 2014
EXPIRES 3-9-15
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INSTITUTIONAL REVIEW BOARD

RESEARCH PARTICIPANT CONSENT FORM

Using Information Visualization to Operate a Multi-Variate Game-Based Simulation

David Whittinghill
Computer Graphics Technology
Purdue University

What is the purpose of this study?

To understand students use a series of information visualizations to operate a multi-variate game-based simulation, and what are some the usability issues the students face in the simulation? Using this knowledge we hope to improve the usability of the M.A.E.G.U.S serious game.

What will I do if I choose to be in this study?

Subjects in this study will play the M.A.E.G.U.S serious game while answering questions about their opinions and thought process while playing the game as well as some questions about their background with gaming and sustainable energy technologies. This process will follow a semi structured template based on the think aloud protocol with a post interview after the testing to ask about the overall experience.

How long will I be in the study?

The study will take 15 minutes to 1 hour.

What are the possible risks or discomforts?

This study has minimal risk which require participants to perform tests no greater than those encountered in daily life or during the performance of routine physical or psychological examinations or tests.

The study will be recorded for audio, video, and screen.

Breach of confidentiality. While this risk is a possibility in any research involving human subjects, we believe that we have reduced the likelihood of its occurrence by limiting the data's exposure to networked computing resources and by having all project personal trained and certified according to CITI. Preventative measures include storing all recordings, which are saved on an external drive , and survey questions in a locked storage container.

The subject can end the study at any point in time if they feel uncomfortable.

Are there any potential benefits?

Potential benefits for the individual include having fun and learning a bit about clean energy. Participating subjects conducting the study will also help improve the usability of the game so that other subjects in the future may have fun with the serious game.

Will I receive payment or other incentive?

There is no compensation. The participant is volunteering to participate in this study.

Will information about me and my participation be kept confidential?

The person who is in charge of this research study is David Whittinghill, Ph.D. James He is being guided in this research by David Whittinghill, Ph.D., and will be conducting the study.

The study will be recorded for audio, video, and screen data.

All data will be transcribed and processed to find similarities and patterns for usability issues. specific quotes may be used in the report but will not include identifiable information.

All participants will be indexed by subject number index rather than their actual names. All published data and analysis will be anonymized – no personally identifiable information will be included in either our publications or our internal analysis. Participant information will be altered and made private when used for the study. If a participant is referred specifically in the results of the study an id number will be used instead of any of their personal information. The key code relating to identify their id number will not be destroyed.

Preventative measures of breach of confidentiality include storing all recordings, which are saved on an external drive , and survey questions in a locked storage container in the PI's office at Purdue University.

When the research is completed, data collected and survey results may be saved for use in future research done by us. We will retain this study information for up to 12 months after the study is over.

What are my rights if I take part in this study?

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, you can talk to one of the researchers. Please contact Professor David Whittinghill(Email:dmwhittinghill@purdue.edu or Phone765-494-1353) or James He(Email: he42@purdue.edu or Phone:8475089617)

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu)or write to:

Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.,
West Lafayette, IN 47907-2114

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

______________________________________ ______________________
Participant's Signature Date

____
Participant's Name

______________________________________ ______________________
Researcher's Signature Date

Appendix B. Usability Test

- At the beginning of the study the investigator will state that these questions are meant to scrutinize the design of the interface not the user.
- Semi structured questions.
  (1-7) represents a likert scale
  1. Background questions.
     a. How would you judge your experience with pc gaming? or turn-based gaming? Not Experienced (1-7) Experienced
        i. Can you tell me a bit about your experience with gaming?
        ii. How comfortable are you with using a keyboard/mouse interface?
            Not Comfortable (1-7) Comfortable
     b. How comfortable do you feel about reading heat maps, graphs, charts?
        Not Comfortable (1-7) Comfortable
     c. Do you have any prior knowledge about solar panels or wind turbines and how they work?

  2. Can you find the interface that represents data about (wind energy vs solar averages, wind energy concentration, solar energy concentration) energy? Can you find the Hex Comparison? Can you find the Minimap? Can you find the Hover Display(aka hex info)?
     a. If they find the interface.
        i. Please take a change to play around with the visualization. Can you tell me a little bit about your understanding of this map or what you think it does?
        ii. are there any part that are confusing about the interface?
     b. If they do not find the graph(point out the graph and explain it)
        i. Why do you think you missed finding the interface?
        ii. What do you think this interface is for?
  3. Once the game testing begins
     a. Tell me a bit about your decision making process for choosing the location for creating the windmill over the solar array(visa versa).
     b. Tell me why you decided to create a solar array over a wind mill(visa versa)?
     c. Walk me through your decision making process for this turn?
  4. Post interview
     a. How much did the information visualizations(graphs/charts) help with your decision making in the game? Helped Very Little (1-7) Helped a Lot
     b. Did you enjoy the game ? Not Very Enjoyable (1-7) Very Enjoyable
     c. What are your opinions about the game as a whole?

d. What are some areas in the game that need improvement?
e. Would improving these areas make you more interested in the game?

Appendix C. Code Book

<table>
<tr><td colspan="2"><u>Interface Codes</u></td></tr>
<tr><td>Map Visualization</td><td>The heat map visualization at the top left of the game. Below represents the different features of the map visualization that were also used throughout coding.
<table>
<tr><td>Wind vs Solar Visualization</td><td>Two different visualizations fall under this visualization; wind vs solar (averages) and wind vs solar. The averages map shows the average of wind vs solar over the remaining turns where as the wind vs solar shows it for the turn being visualized.</td></tr>
<tr><td>Wind Visualization</td><td>Three different visualizations fall under this visualization. Wind averages, wind, and wind speed. wind averages and wind will represent energy concentration. The wind visualizations change per turn.</td></tr>
<tr><td>Solar Visualization</td><td>Two different visualizations fall under this visualization. solar energy and solar concentration. These will stay consistent and will not change over the turns.</td></tr>
<tr><td>Turns</td><td>This feature lets the player sort through the visualizations per turn to give a forecast of what kinds of concentrations of energy are coming in the future turns.</td></tr>
<tr><td>More Info</td><td>Provides a paragraph information of what the visualization represents and provides a legend that shows the key information represented on the map.</td></tr>
<tr><td>Information Tab</td><td>This tab is represented with the icon "i". This tab provides information on how to control the visualizations such as zooming and panning, and also provide a legend for all the icons represented in the map visualization.</td></tr>
<tr><td>Side Menu</td><td>This is a collapsing menu on the right side of the map visualization that stores the buttons for swapping through each visualization.</td></tr>
</table>
</td></tr>
</table>

Table C 1 continued

<table>
<tr><td>Map Visualization Icons</td><td>Icons that represent the city, wind turbines, solar arrays, wind energy, solar energy, and</td></tr>
<tr><td>Hover Display</td><td>This interface appears when hovering over a hex.
The hover display provides the following when hovering over hexes
1. terrain type/solar panel/wind turbine
2. image of terrain type/solar panel/wind turbine
3. adjustable variables that affect wind/solar energy generation
4. whether the terrain is buildable or not
5. the x and y coordinates of the hex
6. the amount of energy generated or available on the hex
7. (if on terrain) a wind vs solar comparison bar graph is shown</td></tr>
<tr><td>Tips</td><td>This interface is located at the top right of the game with information for the player to learn about sustainable energy technologies, give hints for successful performance in the game, and provide sight into specific features of the game.</td></tr>
<tr><td>Hex Comparison</td><td>This interface stores up to three hex's information.
The provided information includes location of the hex, wind and solar energy concentration in both a number format and a bar visualization.</td></tr>
<tr><td>Energy Bar</td><td>A progress bar visualization for representing energy goals.
This is a layered visualization with 1 bar representing total energy generated and another bar to represent how much energy is generated from the following turn.
The colors of the bars change as the city levels up and the energy goals are met</td></tr>
<tr><td>City Interface</td><td>The interface at the middle bottom of the game.
This interface allows the user to read more info on game objects including the city, Wind Turbines, and Solar Arrays.
In this interface the player may choose to read more information about the selection, build more Wind Turbines and Solar Arrays, or Upgrade existing Wind Turbines and Solar Arrays.
An image of the city displays on the left side of the panel that changes as the city levels up.
<table>
<tr><td>Info Panel</td><td>This provides information about the city, wind turbines, or solar depending on the selection.</td></tr>
<tr><td>Build Panel</td><td>In this panel the player may select either to build a wind turbine or solar panel. The cost is associated with each technology. Once a user clicks on either technology they may place the object on a buildable terrain in the game map. The player may also choose to cancel by clicking the cancel button which appears after a technology is selected inside</td></tr>
</table>
</td></tr>
</table>

Table C 1 continued

		the panel.
	Upgrade Panel	In this panel the player may select to upgrade from 2 options based on either technology. This panel will appear when a player selects a sustainable energy technology. Each upgrade has a price associated with it as well as a set limit of upgrades.
Mini-Map	This interface shows a top down view of the game map. This allows the player to position and zoom in the game map from separate view to help reduce clutter of produced sustainable energy technologies.	
Game Map	The three dimensional game map with varying terrains providing space to build sustainable energy technologies or showing that an area is unplaceable. While hovering over hexes that are placeable the hex will light up as white where as hexes that are unplaceable are lit up as red.	
Wind Turbine	The wind turbine three dimensional object that is generated when created on top the game map. Wind turbines take up seven hexes in all on the terrain. One hex for the turbine itself and 6 hexes around the turbine to represent unplaceable space. The turbines provide functionality of rotating that will rotate faster at higher speeds and slower at lower speeds. Upgrading will also be visually represented through longer blade lengths or larger generators.	
Solar Array	The solar array three dimensional object that is generated when created on top the game map. Unlike the wind turbines the solar arrays will not require more than one hex. Upgrades will change the color of the solar array or the size representing different materials and larger amounts of panels.	
Sustainable Energy Technology	This term is used to represent factors that affect both wind turbines and solar arrays.	

Player Codes	
Comprehension	understands functionality or information represented
Low Uncertainty	unsure of functionality or information represented, but quickly retracts that comment about being unsure
Moderate Uncertainty	Unsure of functionality or information represented while understanding parts of the functionality or information represented
High Uncertainty	Completely unsure or incorrect about the functionality or information represented or completely unnoticed
Approval	likes current functionality/ information represented(easy to use, very important) believes functionality/ information represented is very useful
Dissatisfaction	lacking functionality dislike current functionality
Player Expectation	player assumes certain functionality/features based off of prior knowledge
Player Suggestion	Solutions to problems proposed by the player

Level of Severity	
Level	Definition
Critical	Critical usability issues are problems within the application that were highlighted by expressions of confusion from participants. These usability issues significantly hinder the user experience. These issues should be addressed first in order to reduce user frustration with MAEGUS and to enhance ease of use, learnability, and overall game enjoyment.
Moderate	Moderate usability issues are problems that require attention, but are not of vital importance. These issues might require additional functions to be added, but do not directly impact the immediate usability of the game.
Minor	Minor usability issues are small problems that arose from usability testing. These are notable observations made during the tests.

Overall Theme	
Scalability was not consistent.	Scalability in this setting was defined as the interface or functionality will be usable without creating situations of frustration as the buildable area in the game map expands and the complexity of the game increases. The conclusion that scalability was an issue came from participants believing that interfaces lacked features that allowed the user to quickly repeat a task and observations that certain interfaces of the game were left unused until the game reached a certain size by which the participant generally regretted that they had not noticed it sooner.

Appendix D. Participant Report

Participant 1 Report	
Comprehension	• map visualization: understands where is it placeable vs unplaceable • map visualization: understands how to control the visualization after clicking "i" tab • map visualization: colors made sense after seeing the more info tab • map visualization: understood how the turns function worked and was for what • hex comparison: understood how it worked and what it was for • game map: understood build limitations created by the city level, terrain, and wind turbines. • map visualization: understood how to use the maps after seeing the more info panel
Low Uncertainty	• city interface: unsure of how to cancel building
Moderate Uncertainty	• map visualization: unsure what wind vs solar average is (does not look at full title) • map visualization: unsure of the i icon , but understood it was for some form of more information • map visualization: icons are not easily identifiable without legend • energy bar: unsure what the colors represented in the bar or why it is filling up, quickly notices energy numbers attached on top
High Uncertainty	• map visualization: unnoticed buttons and controls underneath visualization. • map visualization: unsure of what controls/ functionality are active after clicking on the map visualization. • game map: unsure how to expand building area • city interface (upgrade): unsure of return on upgrade / which upgrade was better
Approval	• map visualization: was the most useful visualization • map visualization: was easy to understand and use after seeing the more info. • energy bar: likes positive feedback on energy bar constantly going up and never down. • overall: controls for mouse/keyboard were good

Table D 1 continued

	• map visualization: very helpful in decision making • hover display: very helpful in decision making
Dissatisfaction	• overall: colors are inconsistent from map visualization compared to hex comparison/ hover display • hex comparison: missing functionality for identifying what hexes were clicked on via the game map. • map visualization(turns): had issues with clicking the button too much to move through turns/ had no way to return to current turn easily • map visualization: missing functionality for interacting with the game map with the map visualization and vice versa • tips: unhappy that about not being able to hide tips • wind turbine: missing functionality - notification on decreased wind energy is not clear enough just by slowing down. • city interface: lacking functionality mass build and mass upgrade • map visualization: maps besides wind vs solar averages were not so useful • overall: user feedback needs work • sustainable energy technologies: upgrades don't feel very potent • overall: text too tiny on popups
Player Expectation	• map visualization: expected visualization to be on the bottom right. • overall: expects panning to be done with arrow keys or wasd keys • tips: tips added to player expectations on functionality/ decision making
Player Suggestions	• hex comparison: use colors to highlight the ground for where you clicked. • minimap: Use the minimap if the map was bigger • minimap: combine minimap and map visualization
Other Observations	• Does not like interacting with visualizations very much, zooming in and out, only use it for data • forecasting data impacts decision making • takes advantage of energy that turn

Participant 2 Report	
Comprehension	• map visualization: understands where is it placeable vs unplaceable • map visualization: colors/saturation made sense • map visualization: purpose made sense • map visualization: understood how the turns function worked and was for what • map visualization: understood i is for information • map visualization: understood what icons represented based off the legend(looked at legend) • hover display: understood what it meant and what it was used for • hex comparison: understood how it worked and what it was for • game map: understood build limitations created by the city level, terrain, and wind turbines. • map visualization: understood how to use the maps after seeing the more info panel • understands where tips are and how they are used
Low Uncertainty	• hover display: unsure of what wind and solar are out of
Moderate Uncertainty	• map visualization: unsure what wind vs solar average is (does not look at full title) • map visualization: icons are not easily identifiable without legend • game map: unsure how to expand
High Uncertainty	• map visualization: unnoticed buttons and controls underneath visualization. • game map: unsure how to expand building area • city interface (upgrade): unsure of return on upgrade / which upgrade was better
Approval	• map visualization: was the most useful visualization • map visualization: was easy to understand and use after seeing the more info. • overall: controls for mouse/keyboard were good • map visualization: very helpful in decision making(began to use it more after city leveled up) • hover display: very helpful in decision making

Table D 2 continued

Player Expectation	• map visualization: expected visualization to be on the bottom right. • overall: expects panning to be done with arrow keys or wasd keys • tips: tips added to player expectations on functionality/ decision making • city interface: choosing to upgrade was a decision based off coincidentally earning a lot of energy based off a previous turn
Player Suggestions	• should have a better reward system such as giving titles for ranges
Other Observations	• Does not like interacting with visualizations very much, zooming in and out, only use it for data • forecasting data impacts decision making

Participant 3 Report	
Comprehension	• game map: understand where you can and cannot build • map visualization: understands the turns function's use • map visualization: understood visualization after finding more info panel • map visualization: was very useful, making decision making easier • hover display: easy to understand • hex comparison: understands its functionality and that it shows the location of where the corresponding information is • minimap: understands the use , still think it is useful • game play: understands how funds affects the player making complex decisions based on • game map: notices that wind turbines take up more space than solar arrays • energy bar: understands that colors change as city levels up(after understanding use)
Low Uncertainty	• city interface: wasn't sure why he couldn't keep building, realizes out of funds
Moderate Uncertainty	• map visualization: slow reaction to finding location of buttons underneath visualization • map visualization: unsure what wind vs solar average is (does not look at full title or read more info) • game map: un sure if expanding city will overflow into hexes next to it destroying the player's solar panels • city interface: thought that the upgrade button directly upgraded the building.(Incorrect control type) • energy bar: unsure of overflow on energy bar
High Uncertainty	• map visualization: unnoticed buttons and controls underneath visualization. • map visualization: green is good and red is bad(missed title and missed looking at more info) • city visualization: unsure how much upgrades return • energy bar: unsure what the colors of the bar

Table D 3 continued

	means, solar and wind was assumed
Approval	• overall: likes the design • map visualization: believes map is better zoomed out(changes decision after playing the game) • map visualization: believes it is useful in decision making • minimap: good for looks • map visualization helps more than hex comparisons • hover display more useful than hex comparisons • map visualization(wind vs solar averages) and hover display were the most useful • game was fun
Dissatisfaction	• Disliked clicking the map visualization to enable the controls for it • energy bar: city level/ goal not attached to energy bar • city interface: there is no way to continuously build, must also go back to click again. • Distribution of energy seems odd sometimes
Player Expectation	• generator upgrade is better than blade length upgrade(no values were given, based on assumption) • more expensive = better
Player Suggestions	• adding more player elements and more types of decision making that affects the map.
Other Observations	• Does not like interacting with visualizations very much, zooming in and out, only use it for data • forecasting data impacts decision making • uses energy bar to interpret missing information in usability

Participant 4 Report	
Comprehension	• game map: understand where you can and cannot build • map visualization: understands the turns function's use • map visualization: understood visualization after finding more info panel • map visualization: was very useful, making decision making easier • map visualization: the I represents information(likes the position) • map visualization: turns feature became useful when the player started using the visualization. • map visualization: understands future retention and forecasts • hex comparison: understands how hex comparison is used (although clicking was not as apparent) • tips interface was easy to find and easy to read
Low Uncertainty	• map visualization: unsure if clicking arrows for turns skipped the turns • tips: order for tips may need a little work
Moderate Uncertainty	• map visualization: slow reaction to finding location of buttons underneath visualization • map visualization: green is wind and red is solar, but thought that red might have meant not as effective to place(missed title and missed looking at more info) • map visualization: unsure what wind vs solar average is (does not look at full title or read more info) • map visualization: unsure of controls for using visualization • map visualization: expected controls to switch from the game map to the visualization when clicking on the more info bar or side menu. • map visualization: unbuildable areas caused by terrain was not represented on map visualization, cause some confusion • hex comparison: not immediately apparent that click changes what was inside • game map: unsure if city expands as city levels up • energy bar: un sure of colors represented, thought that red meant how much energy was being used

Table D 4 continued

	• energy bar: unsure of overflow on energy bar • city interface: understands upgrades increase energy generation but unsure how much • confusion created by icon interpretation • game started on turn 0 , caused confusion
High Uncertainty	• map visualization: unnoticed buttons and controls underneath visualization. • city visualization: unsure how much upgrades return • energy bar: unsure what the colors of the bar means, solar and wind was assumed
Approval	• map visualization: believes map is better zoomed out(changes decision after game) • map visualization: believes it is useful in decision making • minimap: good for looks • hover display: liked the inclusion of equations • map visualization helps more than hex comparisons • hover display: more useful than hex comparisons • energy bar: was a good visualization • map visualization(wind vs solar averages) and hover display were the most useful • turn button location at bottom right • game was fun
Dissatisfaction	• hex comparison: difficult to track clicked hexes • energy bar: city level/ goal not attached to energy bar • city interface: there is no way to continuously build, must also go back to click again. • minimap: was not very useful, combine with map visualization, would prefer it stayed in the bottom right. • Icons do not match close enough to their representation • map visualization: it was a little small • game map: objects can be deselected by clicking an open hex, missing functionality • map visualization: It was difficult to interpret changes when flipping through the forecast • map visualization: turn buttons were too slow, no easy way to get back to current turn. • no way to continuously build • no way to select upgrade multiple objects

Table D 4 continued

Player Expectation	• expects interface features to be able to toggle • some assumptions made from tips • upgrades to one type does not affect another type • believes in these types of games having mid to high level units are better than having many little units • right click should cancel building or selection
Player Suggestions	• have game map effect map visualization/ vice versa
Other Observations	• Does not like interacting with visualizations very much, zooming in and out, only use it for data • forecasting data impacts decision making

Participant 5 Report	
Comprehension	• map visualization: understands the turns function's use • map visualization: understood visualization after finding more info panel • map visualization: was very useful, making decision making easier • map visualization: the I represents information(likes the position) • map visualization: colors were understood • map visualization: understands how wind and solar maps work clearly • map visualization: understands the turns for prediction • map visualization: i made sense as more info • hex comparison: understands how hex comparison is used • tips section was clear and stood out • hover display: was clear and very useful
Low Uncertainty	• wind turbine: was not completely certain that energy was generated that turn
Moderate Uncertainty	• map visualization: controls for zooming and panning were not apparent and confusing to find. • game map: unsure if he could only build/ start in the lit circle • map visualization icons: some icons were clear and understood while others were confusing(solar icon)
High Uncertainty	• map visualization: unnoticed buttons and controls underneath visualization. • city interface: unsure how much upgrades actually helped
Approval	• map visualization and hover display were useful • enjoyed the game
Dissatisfaction	• minimap: does not interact with the game map directly , may be more useful that way. • map visualization: clicking on the map visualization moves it on the game map, vice versa • hovering on map visualization switches controls from the game map instead of having to click the map visualization • does not like it zoomed out

Table D 5 continued

	• hex comparison was not very useful
Player Expectation	• expects to be able to toggle certain interfaces • prior knowledge from tips
Player Suggestions	• map visualization: suggests starts from a zoomed out state and animates to a zoomed in state. • change wind vs solar averages to wind vs solar remaining turns or all turns • add more technologies to the game • more funds to build more things
Other Observations	• Does not like interacting with visualizations very much, zooming in and out, only use it for data • forecasting data impacts decision making