Automatic Acquisition of User Models of Interaction to Evaluate the Usability of Virtual Environments

Nader Hanna[1], Deborah Richards[1], and Michael J. Jacobson[2]

[1] Department of Computing
Macquarie University
NSW 2109, Australia
{nader.hanna,deborah.richards}@mq.edu.au
[2] Centre for Computer Supported Learning and Cognition
The University of Sydney
NSW 2006, Australia
michael.jacboson@sydney.edu.au

Abstract. Evaluation is an essential step in the research and development of software, particularly for new technologies such as Virtual Environments. One of the challenges to such evaluation is to collect data needed for analyzing the behavior of the users of the virtual environment. Conventional acquisition of evaluation data is time-consuming and prone to bias. In this paper, we present a taxonomy to assist identification and collection of appropriate variables for automatic data collection. We further show how these variables, such as navigation paths and characters met, can be used to capture the behavioral interaction of learners in a virtual ecosystem and to produce a user-model to evaluate the usability of the world under development.

Keywords: Virtual Environment, Automatic Data Acquisition, Usability Evaluation, User-model Data Collection.

1 Introduction

A 3D virtual world or Virtual Environment (VE) can only be considered successful if it is both usable and useful for its intended purpose. Usability measurement of VE could include ease of use and the usefulness of the system, in addition to quantifiable characteristics such as learnability, speed and accuracy of user performance in achieving tasks, low user error rate, and user satisfaction [1]. Due to the differences which exist in the ways that users interact and experience virtual worlds, and the increased complexity of these interactions compared to most desktop applications, like word processors or accounting packages, we propose that the data to be captured, the method of data capture and use of the data for evaluation purposes of VE may differ.

There is some research work that is concerned with usability in virtual environments (e.g. [2]). Typically these studies employ methods used for conventional systems to VE to collect data from which meaningful information about the usability of the system can be extracted. A common method to evaluate VE usability includes

D. Richards and B.H. Kang (Eds.): PKAW 2012, LNAI 7457, pp. 43–57, 2012.

direct evaluation by on-site evaluators who observe subjects using the VE in the laboratory. However, this procedure requires suitable test spaces and access to an adequate number of evaluators to suit the number of subjects. Additionally, this approach can be financially expensive and prohibitively costly in terms of the experts' time involved in conducting the evaluation and their transportation to the location of the experiment. Usability testing for VEs could be done remotely where human subjects and evaluators could be separated by time and space either manually through video-conferencing or through automatic data collection [3, 4]. Furthermore, it is well accepted that usability evaluation for any software should be done as early as possible and begin with developing a demonstration of the virtual system. Bowman et al. [5] note that keeping in mind usability from the very beginning stage in development process of VE, will make developers more likely to avoid creating unintuitive VE that do not match task requirements.

Another traditional method to collect data about VE usability issues is to ask the VE users to report if they have experienced any problems with usability or if some other system aspect did not fulfill their needs. While using self-reporting questionnaires is one of the most common methods to collect data, it has been shown to produce unreliable measures [6]. Self-reporting data can also be collected via interviews. However, these can be time consuming to conduct and, depending on the structure of the interview and the nature of the questions, capture of the data can be difficult. A particular problem with the use of observation and interview methods of data collection is the extensive effort required to later analyse the data. Analysis often involves costly transcription and coding schemes that are prone to bias due to reliance on interpretation of the original data by the coder/s.

To conduct studies of VEs it is critical to collect relevant participant data quickly and accurately [7]. De Leeuw and Nicholls [8] affirm the advantages of computer-assisted data collection over traditional methods. The capture of data using a virtual reality system which supports playback and simulation has great advantages compared to classical paper and pencil methods of data collection [9]. Some research handles automatic collection and analysis of data for standard GUI applications, e.g. [10], but very few efforts have been directed to VE automatic data collection.

To overcome the barriers of evaluating VE usability on-site and to support early formative evaluation of the system, an automated and remote usability evaluation method that uncovers a user model of interaction in the VE is introduced in this paper. After a review of relevant literature in this area and presentation of our data collection taxonomy (section 2), we present the VE in which we have developed and trialed our method (section 3) followed by the method itself (section 4) and results (section 5). Our conclusions and future work appear in section 6.

2 Literature Review and Taxonomy of Data Collection

Collecting data for the events and actions that take place in a VE may involve different approaches according to the purpose of the VE. Andreas et al. [11] divide their collaborative learning system into three different phases, and in each phase they use various data collection methods to acquire data before, during and/or after a session. The data collection methods include initial and final questionnaires, text-chat log files, video recordings and interviews. To address the problem of the rapidly growing amount of user-generated social media data, Zhang et al. [7] developed a technical framework to demonstrate how to collect avatar-related data using a combination of bot- and spider-based approaches. The authors used the Second Life virtual social system to examine the differences in physical activity between male and female avatars and between young and old avatars. Similarly, Yee and Bailenson [12] presented a method that relied on bot-based avatars implemented in PHP and MYSQL to collect and store the longitudinal behavioral profiles of users involved in a Second Life social virtual reality.

Teixeira et al. [4] followed a user-centered design methodology to develop a virtual system called ErgoVR. One of the most important features of ErgoVR, of relevance to this paper, was the automatic data collection of variables of behavioral interaction such as: dislocation paths, trajectories, collisions with objects, orientation of the field of view and the occurrence of events activated by actions done by the user. Using ErgoVR software to automatically register the paths taken by the participants, Duarte et al. [13] showed how some features such as colors, windows, furniture, signage and corridor width may affect the way users select paths within a VE. The study aimed to determine if these factors could be considered as predictors for route selection.

While the majority of research focuses on collecting data from the virtual world, research has been conducted that collects data from the physical world via mobile devices. The data is then analyzed and used for augmenting the virtual worlds with real-life data. For example, Laaki et al. [14] first track the walking path of a human participant while listening to music and later use the data to simulate the trajectory on a map of a walking avatar listening to music.

From our review of the literature, we can classify data which has been collected in virtual worlds according to the following taxonomy:

- *What data is collected.* The type of data that can be collected is limitless. Data could be navigation information within the VE, actions achieved/attempted, text and chat archives, audio and video responses. Further examples of different types of data collected are mentioned in the other categories below.
- *Source/nature of the data (Physical/Virtual).* Data collected could include the behavior of the user in the physical world while using the virtual world, or the behavior of the user in the virtual world. For example, Grillon and Thalmann [15] present a method to track the physical movement of a human's eye while interacting with a virtual character. Eye-tracking data is used in order to determine whether a virtual character is being looked at so that it can adapt to appear more attentive during a public speaking exercise. White [16] presents a technique for classifying human motion through a virtual environment using Support Vector Machines and Kernel learning. The author makes use of the ease of use and flexibility of VE data collection to classify the human's motion while exploring a modified version of an open source video game (*Quake II).* The authors claim the classified virtual motion

could be scaled to multi-agent team behaviors, demonstrating the myriad of ways in which the data captured can be utilized (next point).

- *How the collected data can be used.* Collected data might be used to evaluate the usability of the virtual system, or to understand the behavior of the user. Sebok and Nystad [17] implement a design process to evaluate the usability of a virtual environment. Different types of data are collected. These include task completion measures, understanding of the radiation field, sense of presence, workload and usability ratings. Holm et al. [18] present a method to evaluate the usability of a VR-based safety training system called SAVE. The usability of the system including certain incident or usability problems encountered during the session was evaluated using data collected while testers used the virtual environment. Interaction and simulation data is acquired automatically and joined with external physiological data to be visualized inside a complete 3D representation of the training scenario. Chernova et al. [19] record human-human interaction collected in a virtual world and use this record to generate natural and robust human-robot interactive behavior in similar real-world environments. Bonebright et al. [20] present a very different usage of data captured in a VE. They offer a general methodological framework for evaluating the perceptual properties of auditory stimuli. The framework provides analysis techniques to measure the effective use of sound for a variety of applications including virtual reality. Borner and Lin [21] present work about the analysis and visualization of chat log data collected in 3-D virtual worlds. The log files contain chat utterances from different people that attended a demonstration of different learning environments. From the chat log files, the authors aim at answering questions such as: How many users participated in the discussion surrounding the demo as logged in the chat files? How much overlap exists among the log files? How much do users chat and who chatted the most? How many utterances are devoted to greeting, explanation, commands, questions, or other topics? How long is the average utterance length (number of words in an utterance) for different users? How often do users whisper? In later work [22], the authors present an analysis and visualization of user interaction data that reveals the spatial and temporal distribution of different user interactions in a 3D VE. We note from our examples that *what* data is collected is directly related to *why* it was collected and *how* it will be used.
- *What module collects the data.* The data may be collected automatically from the virtual system itself, or there could be another external module that exports/pulls the data from the running virtual environment. As an example of the former, Teixeira et al. [23] automatically collect, via the ErgoVR system, the following data: Time spent, Distance travelled and Behavioral compliance with exit signs. As an example of the use of external modules, Börner et al [22] introduce two tools which read VE data files and visualize it. The first tool, called *WorldMapper,* creates a 2D clickable map showing the layout of the world as well as interaction possibilities. The second tool visualizes user interaction data such as navigation.
- *Purpose of the VE used to collect data.* The VE could be the targeted VE or a demo VE used as a practice trial to collect data before the user can work with the targeted VE. As an example to testing VE, Griffiths et al. [24] present a tool called the

Nottingham Tool for Assessment for Interaction in Virtual Environments (NAIVE) for screening experimental participants experiencing difficulties. NAIVE comprises a set of VE tasks and related tests, with appropriate performance criteria levels, covering the main aspects of navigation (viewpoint) control and object manipulation and operation.

- *How the log files are analyzed.* The type of analysis performed on the log file/s collected from a VE can vary. Bruckman [25] differentiate between two types of log file data analysis: qualitative or quantitative. Usually, qualitative log file analysis needs a manual interpretation, while quantitative analysis could be performed totally automatically or with some manual translation to data meaning. The author provides two examples for both qualitative and quantitative log files data analysis.
- *Location where the log file is stored.* Log files used to monitor participants' behaviors while using the virtual system may be classified into two categories 1) log files stored on the user's computer, or 2) log files piped to an external database on a central server [26].
- *Time period and trigger for registering data.* Data may be continuously collected at regular time intervals (persistent registration) or data collection may be triggered to begin and end based on certain events (action-based registration)
- *Time when collected data is visualized.* Visualizations can be performed in real-time while acquiring the data during a session or from recorded data after the session has been completed. Either could be achieved remotely where the subject of the VE and human evaluators are separated by time and space [27].

3 The Virtual Environment to Be Evaluated

Before presenting the data collected and use of that data to draw meaningful conclusions about the usability of our VE, it is important to review the goals of our VE [28]. Our VE is an educational virtual world that consists of a simulated ecosystem for an imaginary island called Omosa in which school students can learn scientific knowledge and science inquiry skills. The Omosa Virtual World has been implemented using Unity3D. The learning goal is for students to use science inquiry skills to determine why the simulated animals, known as Yernt, are dying out. Our particular focus is on creating a world that encourages collaboration between the agents and the human and between the humans. Our future need to measure the extent and nature of collaboration has driven our interest in finding an automated method to measure and visualize the users' interactions.

The island of Omosa consists of four different locations the learner can visit. In each location there will be a virtual agent waiting for the visit of the group of companion learners. The learners can ask each agent a set of questions (between 7 and 9 questions). The group members will collaborate to explore the island and visit several different locations. Currently we have developed four locations: the village, the research lab, the hunting ground, and the weather station. In the village the student will meet both the *fire stick agent* and the *hunter agent.* In the research lab the students can meet the *ecologist agent,* and in the weather station the students can meet the *climatologist agent.* Each agent has a list of questions that the user can ask about the agent and each agent will present an alternative view on why the Yernt are dying out.

In addition to interacting with various agents about the possible causes for the Yernt's increased death rates, the students collect information and data notes to compare the current and past states of Omosa and to generate hypotheses about the possible causes of the problem. There are four sets of notes the students can pick up. First, the *rainfall notes* are located in the weather station and contain information about temperature and rain level readings in different periods. Second, the *village field notes* are located in the village and contain information about the activities of the people in Omosa during an earlier period in time. Third, *tree ring notes* are located in the research lab and contain information about the internal structure of the stems of the trees on the island. Fourth, *ecologist notes* located in the research lab contain notes about the changes in the predator-prey ecosystem of Omosa Island. After exploring the virtual world and collecting notes, data, and other observational evidence from the simulated island, the group members will be asked to write a report that summarizes their conclusion about what is the cause of the changes in the ecosystem of Omosa and what is the reason the Yernt are dying out.

4 Data Acquisition and Visualization

A user model is introduced by Mikovec and Curin [29] that can represent user activities in the virtual environment. The proposed model has three levels of detail concerning activities: a) the motion of the user in the environment, b) the detailed behavior of the user in communicating with the other agents/users in the system and c) the users interactive activities with the program such as selecting from a menu or clicking on a button.

In Omosa Virtual World, we used the above three levels of user model as a guide to determine which data should be collected about the user activities. In order to visualize the users' activities and analyze their behavior, data acquisition occurs every one second, and the acquired data is stored in 3 different log files. The first log file allows us to simulate the movement of the user by storing the Cartesian coordinates of locomotion of the learner and contains the time of registration and the x-y-z coordinate. The second log file allows us to measure communication within the environment by storing which agent the learner meets, which question the learner asks and when the question is asked. The third log file allows us to measure the user's interaction with the program/environment by storing which item the learner collects and when it was collected. The amount of data collected during the user activity tracking is very large. For proper understanding of the meaning of these data, visualization methods must be used.

4.1 Cartesian Coordinates of Locomotion

Recording the trajectory of the learner while navigating within the system can be helpful in different ways. This piece of information could illustrate several important issues such as the length of time in seconds spent on a specific task and the distance travelled with a certain locomotion. The following questions may be answered using the data in the Cartesian coordinate log file: which location of the virtual world does the user goes to; which places does he see; which place/s the user does not visit and so does not get the information contained in it? Since the log file registers the time along with the Cartesian coordinate, we may recognize the speed of navigation and in which location the user stays idle for a long time. When the user stays idle for a long time in an important place which contains data to be collected that is reasonable. However, if the user stays idle in an unimportant place this might identify a difficulty in using the system and this is a sign to potentially revise the usability of the current virtual system. Also, the time spent in a specific task could be a measure of its difficulty.

4.2 Detailed Behavior of the User

Another level to help analyze and understand the behavior of the learner while using the VE is to determine which character (agent) the user meets and when and which object the user picked up and when. This information can illustrate the interaction the user has with the objects in the virtual world. The information could be used to show what agents and items the user is interested in while in the virtual system, and which items or agents the user does not pick up or see which may indicate problems in the human-computer interface design.

4.3 The Interactive Activities with the Program

The third level of user activity that is collected concerns the users' interactions with the virtual world. This can involve clicking on certain symbols or choosing a function key. These actions can give information about the usability of the system, for example, repeated exiting of the system (i.e., repeatedly taking the exit button and then going back in to the world) may be a sign that the user faces a problem about how to achieve something or is unsure what they should be doing.

4.4 User Identification and User Models

By collecting the above data we are able to capture a model of the user's activities. These different types of data are stored in multiple Log files. Each of the three levels of user-model presented above has its own file to store its unique data. For each unique user and for each session there are three types of files—inventory Items, positions, and questions—and each type of log file contains data of each element of the user model. Log files in the Omosa Virtual World have a unique structure. The name of each log file contains a unique ID which is a concatenation of the user ID plus the date when the virtual world was used to distinguish each separate user/session.

5 Results

We have conducted two classroom studies involving Omosa Virtual World involving Year 9 students in Australia at the end of 2011. The data that we include in this paper is taken from the second study that involved 54 students in four online sessions over a period of two weeks. For technical and logistical reasons, we did not collect data from all students in every session. The focus of our data collection was on traditional methods such as video capture, pre and post knowledge tests, interviews and focus groups. The students used a printed “guidebook” that had learning activities for Omosa for each class period and written problems for the student to answer as assessments.

In terms of retracing and understanding what the students did in the world, we have focused on using the log files captured using functions in Unity3D. Using this approach, we have been able to gain an understanding of what the students did in Omosa and to be able to visualize their activities at the press of a button in a manner that is much faster than human coding of screen capture videos. Indeed, it is in response to the challenges of how to collect and analyze data in an efficient and meaningful way that we have developed the approach presented in this paper. Given that our interest is in the complex human behavior of collaboration, it was imperative that we developed techniques that would not require intensive qualitative analysis or the involvement of usability or collaboration/communication experts.

In order to evaluate the usability of the Omosa Virtual World and to create user-models of interaction we have written Boo scripts to automatically collect data into log files while students used the Unity3D game. Data analysis was done using both Microsoft Excel 2010 and Matlab 2012a. In accordance with the user-model presented above, three log files for each of the participants were collected, namely one log file for the user’s position, one log file for the virtual agents the user met, and another log file that captured which questions were asked and which notes were picked up. We next present the results for each of these levels.

5.1 Cartesian Coordinates of Locomotion

The user can click a button in Omosa Virtual World to see an aerial picture/map of the island. By clicking on any part on the map the user is taken directly to this location. The position log file is used to register the path the user takes while navigating in the VE. This log file is able to show how many times the user transferred from one place to another and whether there is a certain place the user repeatedly visits. This file can be used to identify if the participant has experienced any navigation obstacles and also helps to identify how many times the user quit exploring the VE and went back to the main menu of the application. We used both Microsoft Excel 2010 for visualizing the first level of user-model of testing usability due to its ease of use and flexibility in creating charts, we also used Matlab 2012a for analyzing the sudden changes in user location coordination which is a reference of quitting the VE and getting back to application menu. The chart/graph produced for a single user is shown in Fig 1. We can include multiple users so that we can compare different navigation patterns, which will be particularly useful when seeking to compare different cohorts or different experimental treatments.

Fig. 1. Visualizing the motion path of one of the learners (dark trajectory), and the transition between different locations (light trajectory)

5.2 Detailed Behavior of the User

In Omosa, the user can interact with the system by meeting various agents and asking them questions regarding the problems facing the imaginary island, namely why the Yernt are dying out. Fig. 2 depicts which agent the student has met, where they met them and what notes/evidence they collected in that location. If we add arrowheads to the edges, the diagram will show the order in which these activities were performed.

The detailed behavior log file provides a lot of data which can be used to evaluate the usability of the VE. Questions which were answered by the data in this log file include the percentage of encounters that have been made with each agent and the percentage of questions asked of each agent. The results for the percentage of questions asked to each agent by all the participants are shown in Fig. 3. It is clear that the Firestick and Hunter agents were asked 39.29% and 31.11%, respectively, of the questions the user should ask, the Climatologist agent is asked only 21.25%. This result reveals that participants did not ask the Climatologist agent as much as other agents. Table 1 provides the actual numbers of questions available and asked for each agent. The results suggest further investigation why the Climatologist was least popular. The results, in general, suggest possible modification of the guidebooks to ensure that students engage more with all agents in order to achieve the learning outcomes.

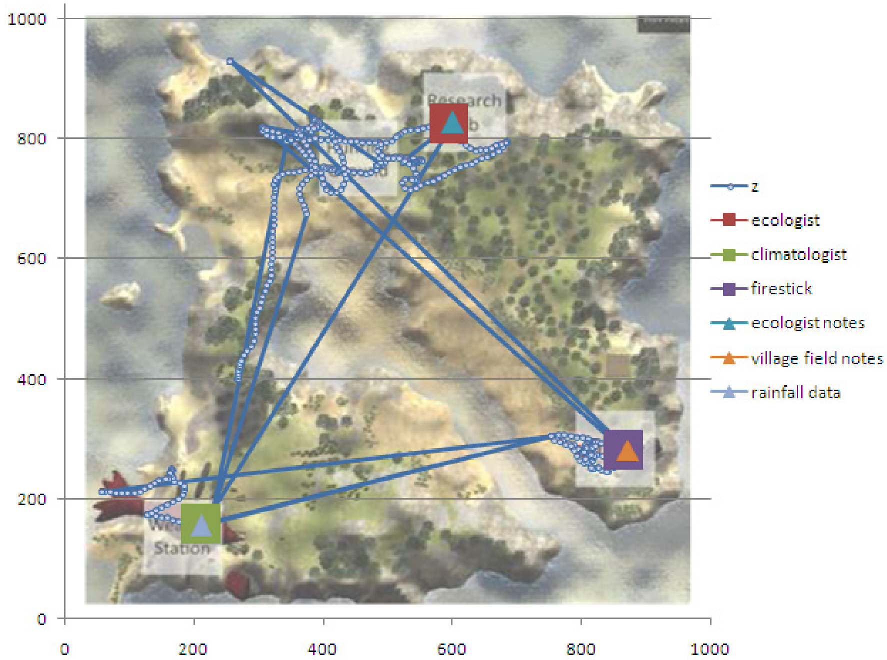

Fig. 2. Visualizing the agents the user meets and the items collected

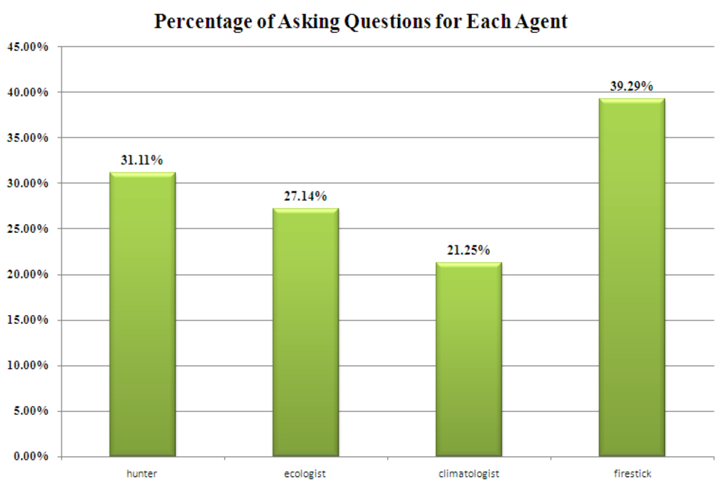

Fig. 3. Percentage of asking questions to each virtual agent

To drill down more deeply into the users' interactions with each agent, the data in the log files were used to show the percentage that each individual question was asked in order to determine which question/s were asked less by the participants. This could be used to change Omosa or the guidebook. In Fig. 4, we see that the least asked questions to the Hunter agent are questions 2 and 3 which inquiries about “*How long have you been here?*” and “*Where am I?*” The questions least asked to the Ecologist agent are 3, 1, 2 and 5 “*Where am I?*”, “*How are you?*”, “*How long have you been here?*” and “*What instruments do you use to study Omosa?*”. The least questions asked to climatologist agent are 3, 6, 4 and 5 which inquiries about “*Where am I?* “, “*Where should I go next?* “, “*What do you eat?*” and “*What do you hunt?*” The Firestick agent is the agent with the most asked questions, the question number 2 and 4 are the least asked questions that are both asked only 30% of the time.

Table 1. The average of asking questions to each agent

	Hunter	Ecologist	Climatologist	Firestick
No. of Questions	9	7	8	7
Average of asking questions	2.8	1.9	1.79	2.75

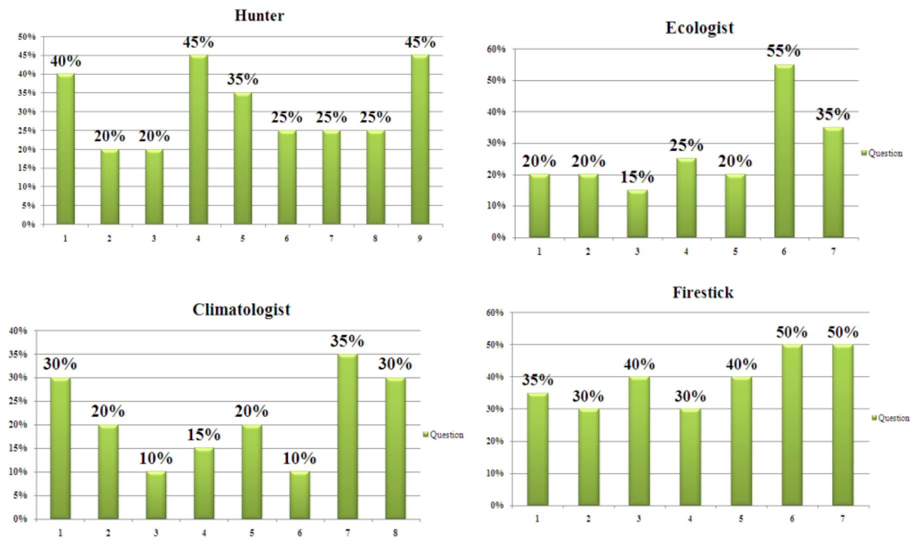

Fig. 4. Percentage of asking each question to each virtual agent

Another aspect of the interaction within the Omosa VE is the ability to collect items and notes. The log files have been used to determine which note is collected and when. Fig. 5. shows the percentage of participants who collected each item. According to the result of analysis, the notes about rainfall data which exist near the Climatologist agent is the least collected item, picked up by only 40 % of the users.

5.3 The Interactive Activities with the Program

The third level in the user-model of interaction is the activities/actions the user performs with the application; these activities could be clicking on a button or returning

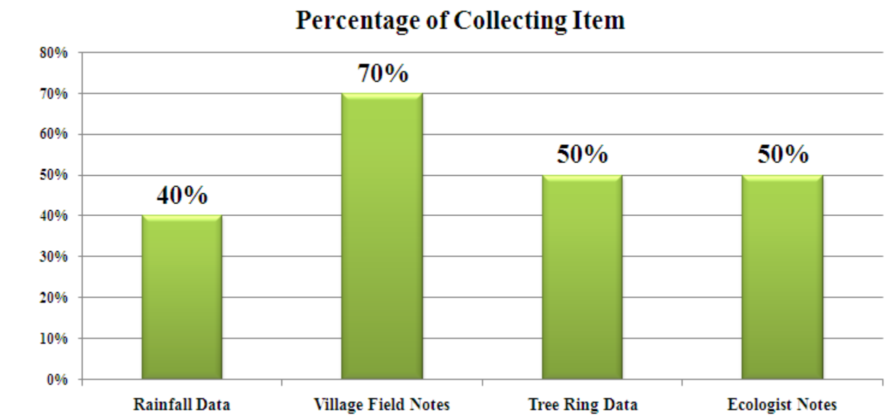

Fig. 5. Percentage of collecting each item

to the main menu. An option in Omosa VE is to show a map for the whole island and the user can be located directly in and place he selects. The user usually clicks to show the map for one of three reasons: first, when s/he finishes exploring certain location and wants to move to another location, second, when s/he gets lost or has a problem in a specific area and wants to move to another location, third, when s/he gets lost or has a problem in a specific area and wants to move to get back to the same location again. In Fig. 6 the frequency of using the program map for each participant is shown along with the average of using the system application. It is clear that 75% of the users (15 of 20 users) are around the average of using the application map while 25% (5 of 20 users) are over the average of using the program. Overuse could indicate confusion over what they should be doing in each place. Underuse could indicate lack of coverage of the four locations. Some further discussion appears in the conclusion.

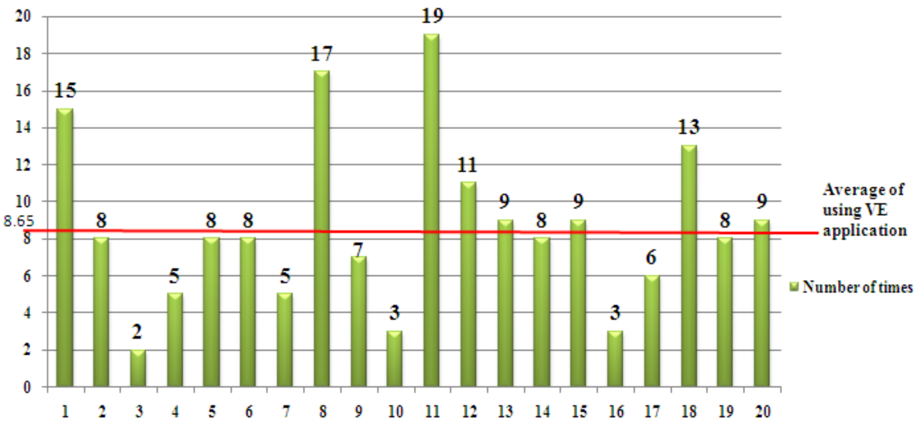

Fig. 6. The frequency of using Omosa VE application Map

6 Conclusion and Future Work

The aim of this paper is to present automated methods that can be used to shed light on the users' interactions in a VE to better understand how the world was utilized and its usability. Concerning the first level of the user model, the results show smooth exploration of Omosa, the only exception is when the user keeps navigating into the water around the island. In this situation the user will have to use the island map to get back to land.

Concerning the second level of the user-model, the result of analyzing log file data shows that all four agents in Omosa are interrogated by some participants but that interaction is as low as 21.25% in the case of the Climatologist agent. Also we found that while all four notes were collected by one or more people, the percentage varies and the least collected evidence is the rainfall notes (with 40% of participant users). This apparent underutilization of the information available in Omosa has prompted a review of our design of Omosa and the associated learning activities and guidebooks.

Concerning the third level of the user-model, the results show that the majority of the participants (75%) use the application map around 8-9 times to go from one location to another to achieve the task they have to complete, while around 25% of the users used the application map more than this average. By reviewing the cases that registered the highest usage for the map, namely user numbers 1, 8, and 11 we find out that they are curious to explore the remote or isolated locations of Omosa Virtual World such as surfing on the surface of water or going deeper into the wilderness, and as a result they have to click on the application map to get back on land again. Contrary to our initial assumptions, the small percentage of over usage of the application map did not mean a problem in the flow of navigating Omosa. Rather it represented the curiosity of some students to explore different and new virtual places.

In future work, we intend to make Omosa a more collaborative VE through adding the ability of online communication between the groups and introducing authentic collaborative tasks that require the human and agent to plan and work together to perform a task in each of the areas within Omosa. Automatic data collection will be upgraded to include collaboration awareness and collaborative interaction [30] to log if the individuals have faced difficulties in finding other groups online and clarifying other participants' thoughts. Information in the upgraded log files about social interaction will shed light on how teams collaborate, or do not collaborate, and that will help in improving the collaborative ability of Omosa. For these purposes, the log files may include text-chat logging, audio, and video logging. Overall, we hope that this research will contribute to the field by demonstrating the viability of using automated techniques for log file analysis in order to understand the dynamics of students learning trajectories in an educational virtual environment.

References

1. Hix, D., Hartson, H.R.: Developing User Interfaces: Ensuring Usability through Product & Process. John Wiley and Sons, New York (1993)
2. Johnson, C.R.: Evaluating the Contribution of DesktopVR for Safety-Critical Applications. In: Felici, M., Kanoun, K., Pasquini, A. (eds.) SAFECOMP 1999. LNCS, vol. 1698, pp. 67–78. Springer, Heidelberg (1999)

3. Jacko, J.A., Sears, A.: The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications. Psychology Press (2003)
4. Teixeira, L., Rebelo, F., Filgueiras, E.: Human Interaction Data Acquisition Software for Virtual Reality: A User-Centered Design Approach, pp. 793–801. CRC Press/Taylor & Francis, Ltd. (2010)
5. Bowman, D.A., Gabbard, J.L., Hix, D.: A Survey of Usability Evaluation in Virtual Environments: Classification and Comparison of Methods. PRESENCE: Teleoperators and Virtual Environments 11, 404–424 (2002)
6. Slater, M.: How Colorful was Your Day? Why Questionnaires Cannot Assess Presence in Virtual Environments. Presence: Teleoperators and Virtual Environments 13, 484–493 (2004)
7. Zhang, Y., Yu, X., Dang, Y., Chen, H.: An Integrated Framework for Avatar Data Collection from the Virtual World. IEEE Intelligent Systems 25, 17–23 (2010)
8. de Leeuw, E., Nicholls II, W.: Technological Innovations in Data Collection: Acceptance, Data Quality and Costs. Sociological Research Online 1 (1996)
9. Lampton, D., Bliss, J., Morris, C.: Human Performance Measurement in Virtual Environments. In: Stanney, K.M. (ed.) Handbook of Virtual Environments: Design, Implementation, and Applications, pp. 701–720. Lawrence Erlbaum Associates, Mahwah (2002)
10. Siochi, A.C., Hix, D.: A study of computer-supported user interface evaluation using maximal repeating pattern analysis. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Reaching Through Technology, pp. 301–305. ACM, 108926 (1991)
11. Andreas, K., Tsiatsos, T., Terzidou, T., Pomportsis, A.: Fostering Collaborative Learning in Second Life: Metaphors and Affordances. Computers & Education 55, 603–615 (2010)
12. Yee, N., Bailenson, J.: A Method for Longitudinal Behavioral Data Collection in Second Life. PRESENCE: Teleoperators and Virtual Environments 17, 594–596 (2008)
13. Duarte, E., Vilar, E., Rebelo, F., Teles, J., Almeida, A.: Some Evidences of the Impact of Environment's Design Features in Routes Selection in Virtual Environments. In: Shumaker, R. (ed.) Virtual and Mixed Reality 2011, Part I. LNCS, vol. 6773, pp. 154–163. Springer, Heidelberg (2011)
14. Laaki, H., Kaurila, K., Ots, K., Nuckchady, V., Belimpasakis, P.: Augmenting virtual worlds with real-life data from mobile devices. In: 2010 IEEE Virtual Reality Conference (VR), pp. 281–282 (2010)
15. Grillon, H., Thalmann, D.: Eye contact as trigger for modification of virtual character behavior. Virtual Rehabilitation, 205–211 (2008)
16. White, C.: Classifying Human Motion in Virtual Environments (Unpublished paper describing the system), pp. 1–6 (2006)
17. Sebok, A., Nystad, E.: Design and Evaluation of Virtual Reality Systems: A Process to Ensure Usability. In: Proceedings of the Virtual Reality Design and Evaluation Workshop (2004)
18. Holm, R., Priglinger, M., Stauder, E., Volkert, J., Wagner, R.: Automatic Data Acquisition and Visualization for Usability Evaluation of Virtual Reality Systems. In: Eurographics-Short Presentations (2002)
19. Chernova, S., De Palma, N., Morant, E., Breazeal, C.: Crowdsourcing human-robot interaction: Application from virtual to physical worlds. In: 2011 IEEE RO-MAN, pp. 21–26. IEEE (2011)
20. Bonebright, T.L., Miner, N.E., Goldsmith, T.E., Caudell, T.P.: Data Collection and Analysis Techniques for Evaluating the Perceptual Qualities of Auditory Stimuli. ACM Transactions on Applied Perception (TAP) 2, 505–516 (2005)

21. Borner, K., Lin, Y.C.: Visualizing Chat Log Data Collected In 3-D Virtual Worlds. In: Proceedings. Fifth International Conference on Information Visualisation, pp. 141–146 (2001)
22. Borner, K., Hazlewood, W.R., Sy-Miaw, L.: Visualizing the spatial and temporal distribution of user interaction data collected in three-dimensional virtual worlds. In: 2002 Proceedings of the Sixth International Conference on Information Visualisation, pp. 25–31 (2002)
23. Teixeira, L., Vilar, E., Duarte, E., Rebelo, F.: Comparing Two Types of Navigational Interfaces for Virtual Reality. A Journal of Prevention, Assessment and Rehabilitation, 2195–2200 (2012)
24. Griffiths, G., Nichols, S.S.n., Wilson, J.R.: Performance of New Participants in Virtual Environments: The Nottingham Tool for Assessment of Interaction in Virtual Environments (NAIVE). International Journal of Human-Computer Studies 64, 240–250 (2006)
25. Bruckman, A.: Chapter 58: Analysis of Log File Data to Understand Behavior and Learning in an Online Community. In: Weiss, J., Nolan, J., Hunsinger, J., Trifonas, P. (eds.) The International Handbook of Virtual Learning Environments, pp. 1449–1465. Springer, Dordrecht (2006)
26. Orkin, J., Roy, D.: The Restaurant Game: Learning Social Behavior and Language from Thousands of Players Online. Journal of Game Development 3, 39–60 (2007)
27. Hartson, H.R., Castillo, J.C., Kelso, J., Neale, W.C.: Remote Evaluation: The Network as an Extension of the Usability Laboratory. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Common Ground (CHI 1996), pp. 228–235. ACM (1996), 238511
28. Preece, J.: Online Communities: Designing Usability and Supporting Sociability. John Wiley & Sons, NewYork (2000)
29. Mikovec, Z., Maly, I., Slavik, P., Curin, J.: Visualization of Users' Activities in a Specific Environment. In: The 2007 Winter Simulation Conference, pp. 738–746 (2007)
30. Schroeder, R., Heldal, I., Tromp, J.: The Usability of Collaborative Virtual Environments and Methods for the Analysis of Interaction. Journal of Presence 15, 655–667 (2006)