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Exploring Geospatial data through Verbal Protocol Analysis (VPA): A case study at Hohai University, China*

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In this paper, Usability Engineering (UE) is used to explore geospatial data at the School of Earth Sciences and Engineering, Hohai University, China. In geo-spatial data presentation, exploration and analysis, knowledge is disseminated, accumulated or accentuated. For learning purpose, this knowledge needs to be evaluated. The increasing use of the computer and multi-media to disseminate geographical information place their own specific demands for the final user. By visual presentation, exploration and analysis users are able to identify features in their minds, since visualization qualifies results and not quantification of results. In the Engineering Education (EE) setup, students create Geoinformation related applications which are archived for later use. The spatial knowledge accumulated is sometimes difficult to apprehend when retrieved. Thus a procedure, such as VPA Archival Management System (VAMS), is needed to recall the ideas embedded in the archived datasets. The test method used is the Verbal Protocol Analysis (VPA). In addition, use of explicit structured questionnaire, video recording, onscreen capturing, and formative evaluation and case study frameworks were used to efficiently, effectively and satisfactorily determine the spatial cognition taking place in user's minds.

Keywords: VPA Archival Management System (VAMS); Human Computer Interaction (HCI); Usability Engineering (UE); Engineering Education (EE); Geoinformation

1. Introduction

Many around the world today employ Geoinformation in their daily activities; be it at home, in the office, on the road, in vehicles, in sports, etc. Spatial cognition research is required to determine how Geoinformation is used at such places; since most often Geoinformation experts know very little about the knowledge acquired by their users [1]. As a result Usability Engineering (UE) in the geospatial domain is highly needed to test these products. Spatial cognition is primarily concerned with the way maps and geographic data are understood [2]; that is what this paper seeks to address. This research was conducted based on the proposition that little research has been done into how geospatial technology interfaces can be designed for non-experts [3]. Expert users were, however, introduced in the protocols of the research. Expert users, be it the analyst or final user, carrying out an analytical task using popular Geoinformation packages have difficulties discovering knowledge derived from the packages. Haklay and Zafiri [1] noted that there has been long record of awareness of Human–Computer Interaction (HCI) in Geographical Information Science (GIScience). Approaches, techniques and levels of analysis of HCI are documented in Crystal and Ellington [4]. As the need arises for UE, likewise is VAMS (acronym for VPA Archival Management System) in the educational setup for geospatial datasets as proposed by the authors. VAMS falls within the domain of HCI in Engineering Education (EE). This novel idea involves the use of Verbal Protocol Analysis (VPA) in archiving geospatial products thereby making it easier to extract the spatial cognition in the geospatial application. As most researches strive to achieve a successful Geoinformation interface, there exist a gab in assessing and archiving Geoinformation products such that the same spatial cognition in the archived datasets can be retrieved just as was developed by the geospatial analyst.

Usability refers to the process that employs people as testing participants or representative of the target audience to evaluate the degree to which a geospatial product meets specific usability criteria [5-10]. The aim of usability is to meet users' requirements such that they can carry out tasks safely, effectively and enjoyably [11]. The World Wide Web (WWW) has emerged as an important medium for Geoinformation and many of its products are distributed through the web on a daily basis; most of which are made too easily without adhering to Geoinformation principles. These are most often not subjected to usability testing and evaluation. True usability is invisible [4, 12]. That is, if a Geoinformation output is presented well or comfortable for users; there will be no complaints. Users expects to: know the purpose of the Geovisualiza-

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tion tool; have training and education on the Geovisualization tool; and have a simple interface [13]. Many methods exist in usability testing, however, the VPA was chosen due to its fascinating, enjoyable and rewarding way of conducting research thereby enabling the researcher acquire a glimpse of how the human brain works, analysing participants behaviour and needs, and discovering information from test participants [14, 15].

Haklay [16] elaborated on the need for geospatial cognition since the way users perceive the physical space is often not how the Geographic Information System (GIS) applications and experts portray it. This is because we hold a mixture of representations in our minds about the phenomenon in question. In addition, conventional mapping and GIS concepts may not fully match human knowledge in the concept of place. Various methods have been proposed for modeling vague and multiple extents within geographic datasets where local place concepts are important to users' tasks [16, 17]. Haklay [16] and Davies *et al.* [17] added, these methods have not yet been evaluated with real end-users in such situation. Thus, the research was conducted by subjecting final geospatial product into testing and involving the final user and geospatial expert in order to build the VAMS. VPA has been used widely in the area of Geoinformation. VPA also known as 'think-aloud' protocol evaluates cognitive processes [18], analyzes what the participants think; ascertaining the internal processing conducted by the user while carrying out a task. It is based on the above views that the idea seems worth to be implemented at Hohai University to widen the research avenue in EE through Geoinformation; to explore the capabilities of VAMS in filling the knowledge gab mentioned above; and to demonstrate the spatial knowledge that can also be accrued from VAMS to the scientific community. The scientific and engineering principles and hands-on skills required in EE were adopted. The objective of the research is the determination of the spatial cognition in archived geospatial products through the implementation of VAMS. That is, setting up a simple usability environment for subjecting geospatial products into VAMS to acquire the spatial knowledge for archival purposes. Usability provides the platform for determining spatial knowledge from geospatial database; and can be thought of as a mixture of declarative (knowing facts), procedural (knowing what to do) and configurational (knowing spatial relationships) [19]. The area of spatial cognition and human understanding of space is the most significant theoretical grounding for geospatial technologies [17]. Usability is a time consuming task to undertake which compels the spatial analyst to ignore in developing applications for the final user. This research adopts a simple and effective approach for testing geospatial products and creating VAMS database for future usage.

2. Materials and methods

2.1 Study area

The scope of the research is the academic setup of the Department of Geographical Information Sciences, School of Earth Sciences and Engineering, Hohai University. The department conducts research in EE with the use of the 3S Technology. The 3S originates from the last letters in the last words in GIS, Remote Sensing (RS) and Global Position System (GPS). The department uses sophisticated measurement and data collection techniques (e.g. satellite positioning and digital imaging) and modern computer-based data management and visualization tools to play a key role in a wide range of important practical projects in fields such as design, construction and management of complex civil engineering projects; acquisition of data for, and production of, digital and paper maps; management of assets, such as land, property, and transportation infrastructure (especially through the use of GIS); monitoring of our changing environment using satellite and airborne remote sensing management of natural resources, both on land and offshore; planning urban environments (e.g. location of schools, hospitals and supermarkets); understanding and predicting earthquakes by measuring very small land movements; and ensuring the safety of man-made structures (such as bridges, dams and large buildings) by monitoring their deformation. Current research activities that are archived and ongoing are in the area of drought, wetlands, grassland and desertification monitoring at the Source Region of the Yellow, Yangtse and Lancang Rivers (SRYYLR) in China.

2.2 Role of VPA as a research method in geospatial technologies

VPA was originally developed to study problem-solving strategies [20, 21] and assesses cognitive processes. VPA means that test participants report their thoughts while reading, but they are not expected to analyse their behaviour as in introspection [22]. By means of asking test participants to say out loud whatever goes through their minds, researchers get more direct view of the mental processes participants are engaged in while reading [23]. It analyzes participants' thought process, ascertaining the internal processing conducted by the participant while carrying out the task; which facilitates the understanding of human performance levels [24]. Running a commentary from participants as they 'think aloud' while they perform tasks offers many insights to why a problem exists and how to work around it [4]. Visual analysis allows users to see groupings of features, as well as areas where features are not grouped of which all takes place in the user's mind; since visual analysis does not quantify results [12]. Uses and roles of VPA are documented in literature [e.g. 4, 14, 23–27]. Haklay *et al.* [6] highlighted on the common stages of VPA for developing geospatial technologies.

2.3 Data, test instrument and procedures

Student's thesis applications ranging from bachelor to doctoral were the base datasets used. Material used for the test included: laptop with Windows 64-bit Operating System; two camcorders and laptop inbuilt webcam for recording user actions on the computer screen, facial expressions, behavioural and verbal protocols of actions; microphone for speech detection; a multipurpose software for capturing video, audio and onscreen activities into the computer; and semi-structured questionnaire. Seminars and orientations were held to orient participants on how to use the setup. A visual basic programme was developed for archiving and assessing the VPA. Fig. 1 is the proposed methodological mechanism in building the VAMS. It comprises two stages. Stage 1 is the core for the VAMS where the designer creates the VPA protocols for archival. This is then tested in stage 2 by users. The analyst uses the feedback from stage 2 in stage 1 to improve upon the VPA before archival. The applications used ranged from GIS, RS, GPS, Matlab/Geoinformation to 3D Visualization based applications used in grassland, wetland and desertification monitoring at SRYYLR.

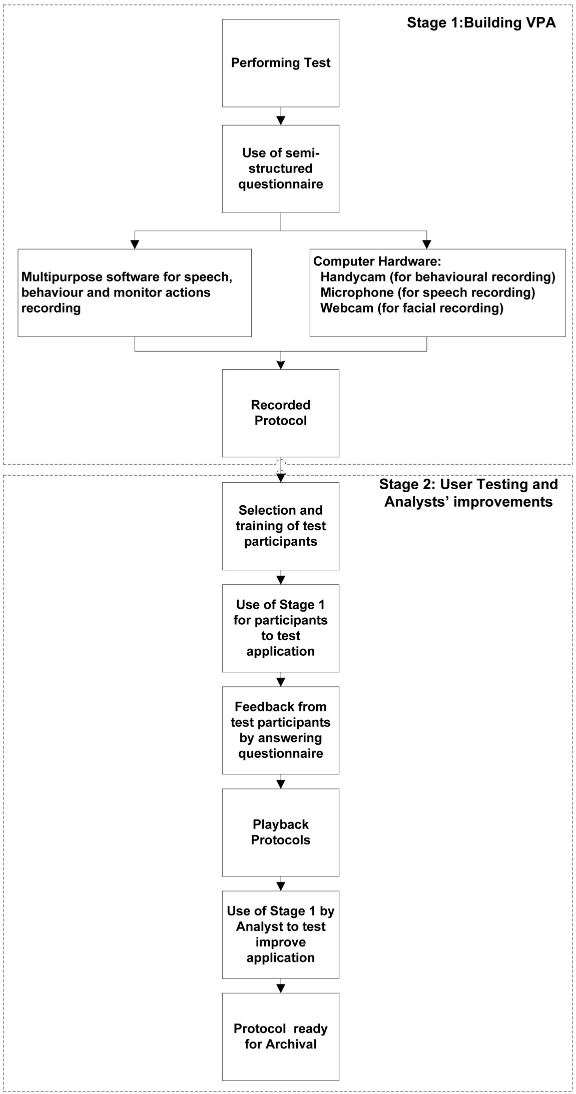

Fig. 1. Methodological mechanism of acquiring user feedback in the usability.

A number of frameworks, methodologies and data collection techniques exist for studying user performances in usability and these are elaborated in Marsh and Haklay [26]. Formative evaluation and case study frameworks, use of explicit structured questionnaire, video recording and onscreen capturing were used to determine the spatial cognition taking place in user's minds; to help better re-design (Fig. 2) the application to achieve efficiency, effectiveness and satisfaction. Efficiency, effectiveness and satisfaction are thoroughly discussed in literature [e.g. 1, 4, 6]. Marsh and Haklay [26] and Bowman *et al.* [28] documented on the importance of questionnaire in VPA.

2.4 VAMS

VAMS is an acronym for VPA (Verbal Protocol Analysis) Archival Management System. Its core principle is derived from UE; and the basic requirement for VAMS is VPA. The 'Archival' is the collection of the geospatial related applications; the 'Management' is the successful handling of the archived geospatial applications through VPA; for example storage and updates as well as reachability, understandability, availability and approachability of the spatial cognitive evaluation of archived application; and the 'System' involves the various methods, software, hardware, participants, data and the UE. The plan view of the proposed VAMS setup demonstrated in Fig. 1 is shown in Fig. 3.

The VAMS is introduced in the educational setup to bridge the knowledge gap that exists in reviewing archived geo-spatial related applications; such that the same spatial cognition can be retrieved just as was developed by the geospatial analyst when they have graduated and gone. The main idea behind VAMS is to introduce a way of maintaining the same spatial knowledge in an archived geospatial

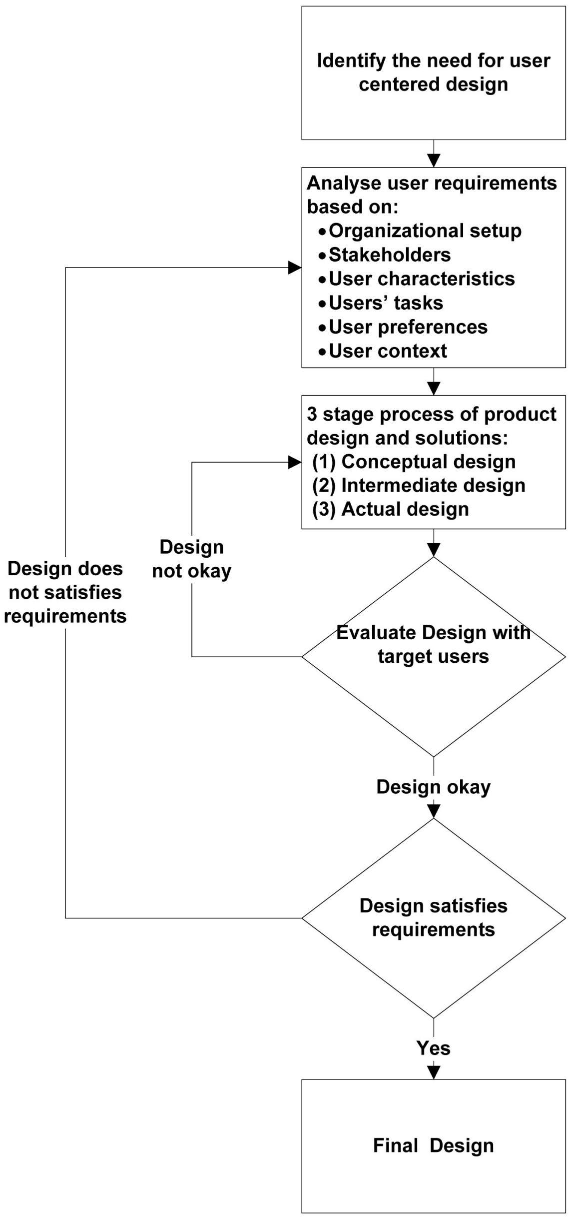

Fig. 2. Usability Design Process (adopted from Mandel [27] and van Elzakker and Wealands [29]).

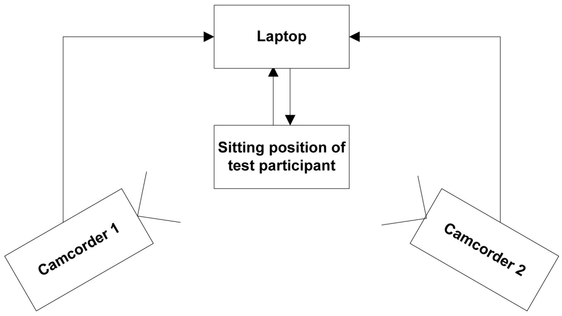

Fig. 3. Plan view of the VAMS procedure, where the arrows indicate flow of information to the computer.

dataset when it retrieved at a later date by a different user. Thus the spatial analyst will thus have to adopt VAP to report his/her geospatial product for archival to help future needed students perceive his/her intentions. This enhances students learning in EE.

VAMS employs knowledge, principles and modern technology related to the professional educational practice of earth sciences and engineering. With reference to EE, a process which is reinventing itself [30–32], VAMS plays a significant role. This is because VAMS employs scientific and engineering principles, and hands-on technical skills required in EE to solve problems related to spatial cognition.

The setup of VAMS at the University level is an interesting and innovative approach which could improve EE. The use of HCI and UE in VAMS in building protocols for archiving and managing software applications and thesis work promotes researches in EE. Using VAMS to preserve spatial knowledge in archived spatial data can help answer the 'why' and 'how' questions in engineering learning [33]; a task put forth by the EE community to answer [34]. VAMS in EE supports: the fundamental research on how students learn engineering as recommended by Gabriele [34]; Haghighi's statement of "addressing overarching and grand questions" [35, p.351] in education; and the shift from "teaching to learning" [35, p.352]. VAMS adopts the guidelines provided by the National Research Council for scientific research in education [34, 36].

2.5 Selecting and training test participants

The test participants were graduate students and staff of the Department of Geographic Information Sciences at the Hohai University. These participants are experts in the discipline of Geoinformation such as Cartography, GPS, GIS and RS. They possess geo-spatial analytical skills. They are able to foretell and evaluate the Cartographic output with their geo-spatial analytics. Haklay and Nivala [15] raised the need for expert users in VPA. Table 1 indicates the number of test participants and applications used. A considerable number of ten participants were selected for each application since Nielsen [37, 38] long years of research experience in usability noted that five test participants are just enough for testing.

2.6 Design and implementation of VPA

The design of the VPA was based on the objective of VAMS. That is adopting a procedure of evaluating the efficiency, effectiveness and satisfaction whereby a VPA application is designed for users to assess the spatial cognition of the spatial analyst using spatially-archived datasets. The testing was broken down into tasks and questionnaire. The tasks comprised of trial and testing sessions. The trial session

Table 1. Summary of the number of applications and test participants used for the VAMS

	Applications	Number of test participants	Number of test applications
1.	3S Technologically related applications	13	10
2.	GIS oriented applications	20	10
3.	RS oriented applications	16	10
4.	GPS oriented applications	5	10
5.	Matlab and Geoinformation based applications	10	10
6.	3D Visualization	10	10

was introduced to help participants to familiarize with the user interface of the VAMS before the protocol. This is because the objective of the VAMS was not to test the software interface, but rather the concepts behind the design of the application. This was then followed by explanations on how to perform the test and answer the questionnaire. Participants were given brief and concise demonstration on how the interface works. Participants were left alone to perform the test whilst they were being timed. The testing session comprised of pre-defined tasks for the participants to perform whilst 'think aloud', followed by the questionnaire. The questionnaire comprised of semi-structured questions, which were answered by participants by ticking their choice of answer on a paper whilst 'think aloud' to explain their choice of answer. The structure of the questionnaire was based on: (1) Satisfaction, which is the complete fulfillment of a need or want. These questions were used to determine the participants' satisfaction after exploring the geospatial application. For instance, whether the application gives enough information about the phenomenon of interest, whether the application is appealing, and how users feel about the application. The overall intention is to determine whether the user can derive the spatial knowledge within the datasets; (2) Effectiveness, which is the extent to which goals are achieved. These questions were used to find out whether the application is user friendly; and (3) Efficiency, which is the mental effort put into reaching goals; as well as finding out if the application is time consuming in visualizing a phenomenon. Fifteen minutes was allotted for familiarization during the trial session and twenty-five minutes for the VPA session for which the seven tasks were given to the participants to perform. Ten minutes was allotted for answering the questionnaire so as to determine the satisfaction, efficiency and effectiveness.

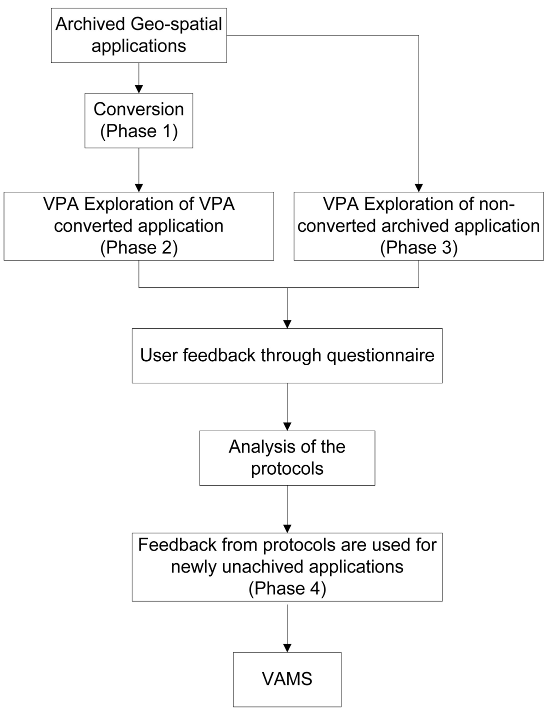

Fig. 4. Phases of the VAMS.

Sixty participants participated (Table 1). It was ensured that there were no disturbances from the outside environment during the sessions. The experiment was conducted in four phases (Fig. 4). Phase 1: Converting the archived geo-spatial related applications to VPA format. This was used in the experiment to derive the spatial knowledge within the datasets archived over a period of years for which the original analyst have graduated and left. This was also done to address the basis of the research by discovering the problems in retrieving the spatial knowledge from archived applications. Phase 2: Exploration of the converted archived geo-spatial related applications by the participant in the VAMS setup. Phase 3: Exploration of the unconverted archived geo-spatial related applications by the participant in the VAMS setup. Phase 4: Adopting feedback from previous phases in using VPA for archiving newly geospatial related applications.

Phase 2 was introduced for comparison and analysis. Phase 4 was used for the final year student projects since they are carrying out their thesis work and was available in using the VAMS setup to provide a running protocol of their applications. Feedbacks from phases 1 to 3 were used in phase 4.

3. Results and discussions

In phase 4 (Fig. 4), the Graphical User Interface (GUI) (Fig. 5) designed using Visual Basic programming language to plays back the final VAMS

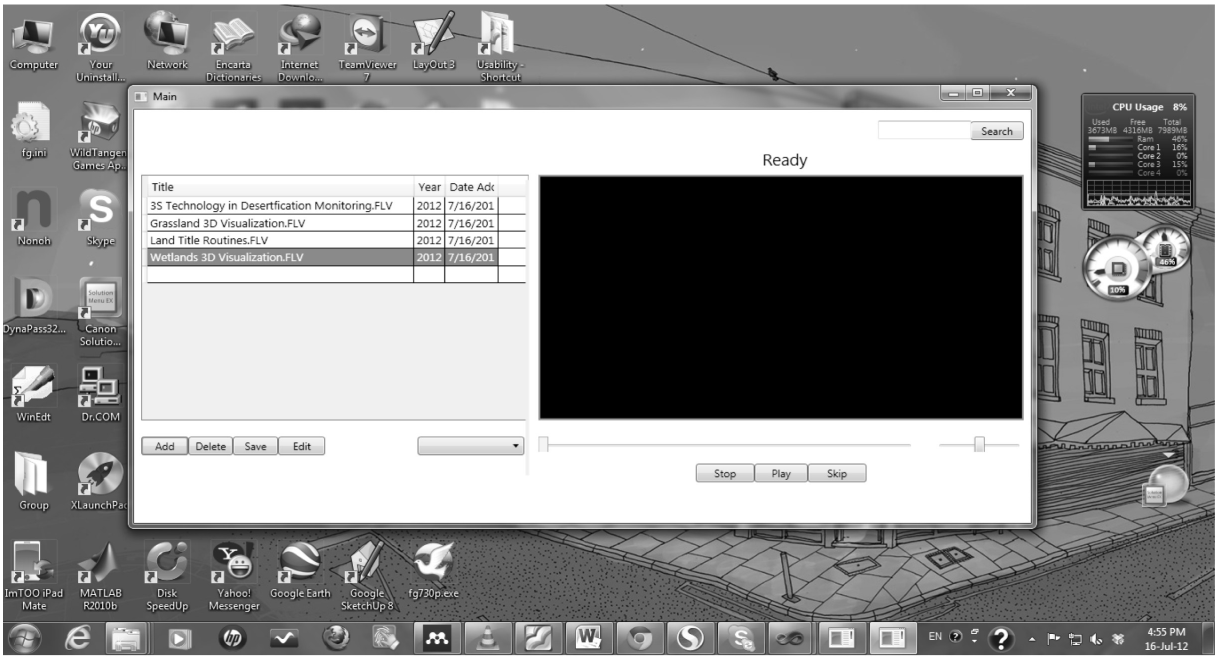

Fig. 5. GUI for managing VAMS.

protocols. Fig. 5 is a database information system not only for playback but for storage and update. The Visual Basic application was developed as a database medium for archiving, playback and updating the verbal protocols for users to discover spatial cognition in existing datasets. In this exercise, the analyst needs to adopt VPA testing strategy in UE to determine efficiency, effectiveness and satisfaction of the application. The results and discussions are narrowed down to the 3D Visualization protocols due to the many results accrued from the research, of which all cannot be documented in this paper.

3.1 The 3D Visualization protocol

In the case of the 3D Visualization protocol participants were given two applications: (1) 3D virtual medium with realism; and (2) a 2D traditional GIS application of using points, lines and polygons for visualizing SRYYLR. Some participants claim the 3D medium was not to their liking since they are not used to it. This claim was highest compared to the traditional GIS approach due to familiarity with GIS approaches. Participants identified the spatial features within the medium, although there were difficulties in using the buttons to navigate through the 3D virtual environment. Participants claimed the speed of the interface was too high, although they could adjust the speed of movement. Viewing the whole environment in which the features were located was very easy to be accomplished by the participants. Without the protocols it was difficult for the participants to perceive the intent of the analyst. The cognitive knowledge of the analyst was not easily identified by the participants in phase 3. However, they were able to conceive the idea in phase 2. Considering the questionnaire, the analysis was based on highest number of participants' choices made (Table 2). These numbers were further classified as percentages and visualized using the pie chart. The results obtained from the questionnaire in Table 2 are analysed in the preceding sub-section.

3.1.1 Satisfaction

50% of participants partially agreed that the display of SRYYLR using the application was appealing and very satisfactory; 50% of participants totally agreed that the application was good for visualizing SRYYLR; 40% partially agreed that the application was a good medium of informing SRYYLR; 50% partially agreed that the application gave a realistic view of the environment as compared to traditional way of showing points, lines and polygons. However, 50% neither agreed nor disagreed that SRYYLR represented within the medium was more appealing as compared with the traditional way. Explaining these higher percentages (Fig. 6) from the protocols by the participants in the 'think aloud' method, the techniques behind the application was very pleasing for visualizing features at SRYYLR. The traditional method contains much textual information about SRYYLR. An example given by a participant was the visualization of SRYYLR without having the opportunity of seeing the environment in which the rivers are located. The 3D application gave a good visual

Table 2. Questionnaire showing participants' number of choices based on satisfaction, effectiveness and efficiency

	Totally Agree	Partially Agree	Neither Agree nor Disagree	Partially Disagree	Totally Disagree
Satisfaction					
1. The look of the 3D medium is appealing.	1	5	3	1	no record
2. The way in which the features are represented in the system is very satisfactory (i.e. visualization of is realistic and detailed enough)	2	5	2	1	no record
3. The way realism is presented in this application is worth of use for visualizing SRYYLR you wish to be informed about.	5	3	1	1	no record
4. The application is a good medium of informing you about SRYYL	1	4	3	2	no record
5. Comparing the two systems of visualization, this application looks more appealing.	2	2	5	1	no record
6. Comparing the two systems of visualization, this application gives realistic view of the environment.	2	5	no record	1	2
Effectiveness					
1. Navigating into the system for visualizing SRYYLR and its surroundings using this application is easy to use (i.e. the application does not involve effort).	2	5	no record	1	2
Efficiency					
1. Visualizing SRYYLR and its surroundings is skillful in terms of time (i.e. the application does not involve much time in visualization).	3	6	no record	1	no record
2. The mental effort in identifying and visualizing SRYYLR using this application is efficient in terms of time.	1	7	1	1	no record

impression about SRYYLR and its environment. The participants concluded that the 3D application was satisfactory in terms of use, realistic representation of the environment.

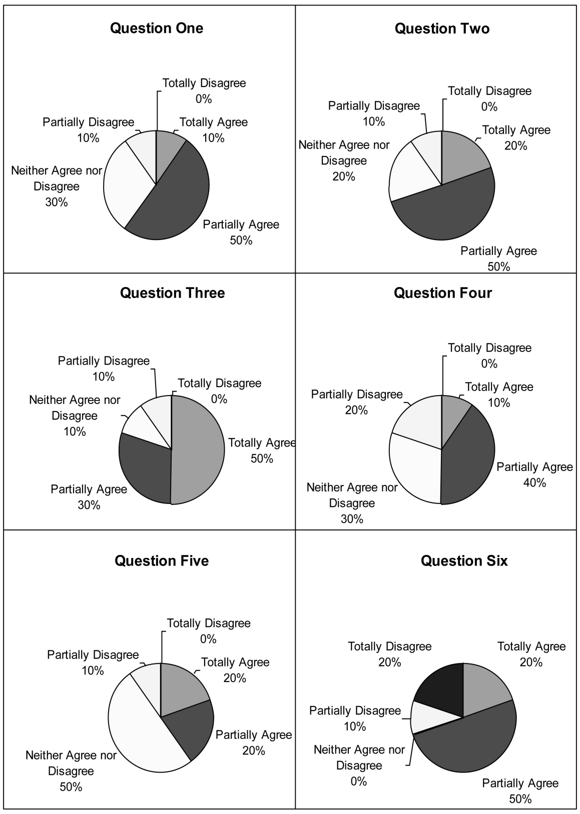

Fig. 6. Answers based on satisfaction visualized using pie chart.

3.1.2 Effectiveness

40% of the participants partially disagreed to the question that navigating within the systems for visualizing SRYYLR was easy. This higher percentage (Fig. 7) can be explained from the protocols by the participants in the 'think aloud' method. That is, most of the participants were not conversant with virtual reality interface due to the way they interact with the application. Some participants were lost in the virtual environment. Hence, navigating into the system seems very difficult. Some claimed with more practice it will be very easy to use. Adding, the buttons have too much functionality for use. The application is effective for participants who are conversant with virtual interface.

3.1.3 Efficiency

60% of the participants partially agreed that the application did not involve much time in visualizing

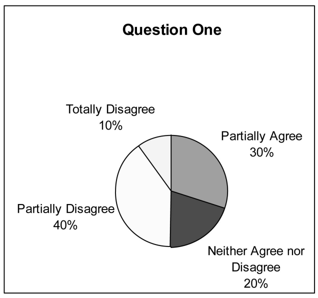

Fig. 7. Answers based on effectiveness visualized using pie chart.

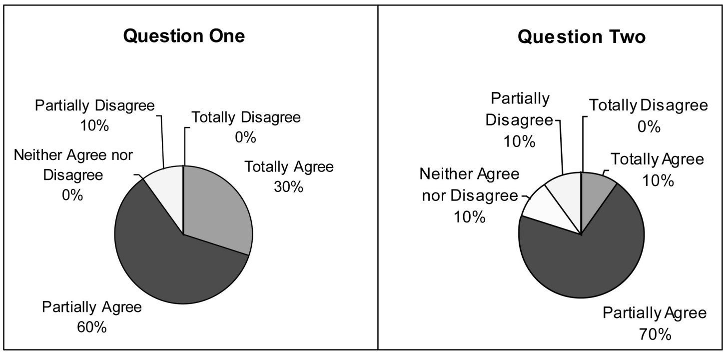

Fig. 8. Answers based on efficiency visualized using pie chart.

SRYYLR; and 70% of the participants partially agreed that the mental effort in identifying and visualizing properties using the application was efficient in terms of time. Explaining these higher percentages (Fig. 8) from the protocols by the participants in the 'think aloud' method, features were easily identified without difficulty. The conclusion drawn from the test was that the application is efficient in terms of the time required to visualize SRYYLR, although the virtual navigation was problematic for participants.

In all, participants claimed the application is good for representing the environment. Users could easily have a look at the surroundings as compared to the traditional approach of using pictures. Participants were able to grasp the concept of visualizing SRYYLR without fore-knowledge of physical familiarization on the field. The response of Phase 2 was higher than Phase 3.

It was discovered that such a VAMS in EE when implemented over a long period can promote knowledge discovery as formulated by the spatial analyst. Thus the HCI incorporated with VPA in VAMS serves as a powerful communication medium in knowledge discovery. Feedback from Phase 4 (Fig. 4) was used to improve the interface. User's feedback from the protocols revealed how users were able to derive the cognitive knowledge within the data as initiated by the analyst. Most often than not geospatial applications are archived in a computer database for years in the academic arena. These retrieved applications are somehow difficult to run or even use because the original authors have graduated and gone. In most cases the reports which serve as a guide in running the application does not help in any way. Personal encounter in supervising students on topics in GIS, RS, Cartography and the broad 3S Technology reveal that students find it difficult to review existing archived Geoinformation products. Also it takes students months to accomplish a simple task necessary to run an application. This was also encountered by [1, p.88–89] in their research. Thus the VAMS (Figs. 2 and 4) served as a means of improving the geospatial application thereby achieving the required spatial cognition. The final verbal protocols served as a form of archiving geospatial datasets. This is a HCI for knowledge acquisition in EE where students can playback geospatial applications to acquire the spatial knowledge of the analyst.

Although this study focused on geospatial data archival and management with VAMS, other disciplines in the engineering educational setup can employ VAMS in the archiving thesis work; since VAMS is an interesting and innovative approach in improving EE. The idea can further be extended to the practicing geospatial organizations were new applications and ideas are frequently formulated of which the designer intentions need to be archived. The advantage in creating the proposed VAMS application will requires feedback from users and thus helps in the re-design of the application. Thus the analyst is provided with advantage of testing and re-designing the application, and providing the platform of protocols for retrieving the original spatial cognition with the application. The researchers are of the view of considering gender cognition in the testing and building of VAMS. This is due to the fact that literature on gender differences in the use of Geoinformation is sparse; as also indicated by Davies *et al.* [17].

4. Conclusions

A new idea, VAMS, of using VPA in retrieving spatial cognition in an archived geospatial application was achieved. Spatial cognition can be retrieved from an existing archived geospatial data with the use the VAMS. This is a research opportunity for the geospatial domain in EE. The idea has widened research avenues at Hohai University through the application of HCI in VAMS. Results indicate that high spatial cognition can be gained from archived geospatial applications and datasets using the VAMS and the results demonstrates an efficient, effective and satisfactory method of archiving and retrieving geospatial whilst maintaining spatial cognition as perceived by the original geospatial analyst. Continuous and sustainable research in EE requires a new vision for EE innovation through the implementation of VAMS that is based upon the solid foundation of engineering educational research and practice. Implementing the VAMS in EE over a long period promotes spatial knowledge discovery without difficulty compared to the normal way of archiving geospatial products. The adoption of VAMS can provide the impetus for improvement in the way engineers are educated and conduct research.

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