Pedagogical Innovative Research Endeavor: Visualization of Streamed Big Data through Augmented Reality

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***Abstract*—The speed of technical and scientific innovation is accelerating much faster than humans can learn. Thus, there is a need for innovative pedagogical research to decrease this gap. Toward that goal, the approach of pedagogical component experiment was to design, develop, and measure the effectiveness of an augmented reality (AR) application for the visualization of streamed network traffic data to create an innovative pedagogical research environment and opportunities for learners. Specifically, this experiment was developed for the Microsoft HoloLens, with several AR models of data visualization. The effectiveness of this application was measured. Preliminary results showed that using augmented reality to visualize network data enhances comprehension of the data, though, results using statistical analysis were inconclusive, and further research is needed to determine whether using AR to visualize streaming data is more efficient than other methods of visualization. However, in spite of the outcome of this research experiment, a pedagogical environment was positively created for learners that most likely increased their involvement in research and learning.**

Keywords*—Pedagogical Techniques, Data Visualization Augmented Reality (AR), GUI (Graphical User Interface).

I. INTRODUCTION AND ARRANGEMENT

Humanity's ability to learn seems to remain fairly constant, but the pace of technical and scientific innovation is always accelerating [7]. This gap is more apparent with the younger generation of learners. Innovative and stimulating pedagogical environments that embrace novel techniques, concepts and materials will have to be developed to address this imbalance [8, 9, 10]. Recently, there has been a tremendous increase in the use of visualization technologies for effective pedagogical practices; major researchers have undertaken multiple projects regarding this subject. For this reason, an innovative study was planned for learners in exciting topics to investigate while an innovative and dynamic pedagogical environment was created [11, 12]. Learners were guided through all the major components and stages of research by actually undertaking a research endeavor. This article showcases the learners' knowledge and skills of research being involved in a created pedagogical research environment. Since this is only a preliminary experiment, only subjective data were collected and general results are presented by keen observation. A plan is under way to design a detailed study to collect objective data and to report analysis of the collected data, conclusions, and specific practical recommendations.

II. CONCISE LITERATURE REVIEW

Augmented reality has been known to enhance student's emotional response to learning and improve their cognitive process. A study analyzing Augmented Reality application among high school students when learning an abstract and cognitively difficult subject like Electromagnetism showed improved student engagement, higher levels of concentration and enhanced flow state [13]. This Study also highlighted the fact that learning designers need to balance AR application against task difficulty, as the impact of AR is uncertain when the level of difficulty is too low or too high.

With the rapid improvements in computer technology, the human computer interaction (HCI), can be further enriched by introducing AR. This technology can provide a breakthrough wherein users can better immerse themselves in the virtual environment and achieve a heightened learning experience. For instance, the use of AR technologies for online teaching can "improve the students' participation and enthusiasm, and enhances the teaching effect." [14] "The Application of Augmented Reality Visual Communication in Network Teaching", "Qian, Zhai" (2018). As further example, medical Curriculum data are used strategically to organize medical programs in various universities. A study on how "AUVA - Augmented Reality Empower Visual Analytics to explore Medical Curriculum Data", Nifakos, et al [15] suggests that using AR technologies and Visual Analytics for processing, analyzing and presenting Big Education data, could considerable improve the skills and understanding for the new generation of medical professionals. These technologies were used to link Learning Outcomes and intended competencies after graduation from medical programs, to the course content and teaching strategies.

In widespread research of the topic, several prominent articles were studied for the use of Augmented Reality (AR) in the analysis and visualization of Big Data. In Mattina et al. [3], "Mobile Augmented Reality for Cybersecurity, MARCS," an AR platform that displays mobile network data with an interface catered toward comprehension was introduced.

Humans gain a benefit from visualization of hard-to-digest information such as raw data. Augmented reality has the potential for constructing novel visualizations of data that are more immersive and intuitive than traditional 2D or 3D visualizations. In Olshannikova et al. [2], "Visualizing Big Data with augmented and virtual reality", the main aim was to give a summary on the challenges in existing visualization methods for Big Data in addition to the challenges posed by Mixed Reality technology. In using Mixed Reality technology, one benefit was quick access to information that assimilates with the subject's field of view. One drawback is that the current technology is still in development and is not always accessible to non-professional users.

"Images are often easier to perceive in comparison to text." [2] In "Smart Vidente," Schall et al [5] present research on how AR technology could be used to benefit a company as a tool for visualization and management. AR technology could be used in a variety of enterprise applications, from on-site inspections, to planning, to data capture.

The complexity of raw big data makes it a challenge to comprehend. The primary objective of data visualization is to convert hard-to-digest material in a manner that is concise, clear and meaningful [3]. 2D data visualizations have been applied to big data in a variety of forms, including graphs, tables, and maps [2]. Research suggests that there are advancements to be made in using Augmented Reality technology, specifically in that augmented imagery would provide for a more complete and intuitive rendering of big data than 2D images would [2,3].

III. RESEARCH DESIGN METHODOLOGY

This study's main purpose was to design, develop and measure the effectiveness of a prototype augmented reality application for the visualization of network data. An experiment was conducted to measure the efficiency of the model. The visualizations were formed using data such as the IP and MAC addresses of machines connected to the network, their locations, AS numbers, and other relevant information. The information is synthesized in an AR application that can be accessed on the HoloLens.

A. *Augmented Reality System Design*

The system architecture can be summarized by a data layer, business layer, and presentation layer. Wireshark is the primary software component of the data layer. Using Wireshark and a command prompt interface, the analyst captures the packets of the selected network in a pcap file. The pcap file is exported as a CSV file with selected data fields for visualization. A JSON file is created for specifying how the data in the CSV file will be used in the visualizations.

The business layer consists of the software components Unity3D and Visual Studios. Unity3D is the primary software editing tool used for creating the GUI and the data visualizations. The toolkits used within Unity include the DxR toolkit and the Mixed Reality toolkit [6]. These toolkits are used for creating graphic visualizations of the data that can be viewed and interacted with on a mixed reality device such as the HoloLens. In Unity, the project is built as a Visual Studios Solution. From Visual Studios, the solution is deployed to the device. The presentation layer consists of the user's interaction with the application on the device. Wearing the HoloLens, the user selects the application and interacts with the GUI to choose a visualization. The visualization is then displayed as a hologram and the user is able to view and interact with it or return to the main menu.

B. *Experimental Method*

a) Research Question and Hypothesis: The secondary emphasis of this study was on measuring the effectiveness of the application in an experiment. The rest of this article describes the experiment.

Experimental Research Questions:

- Is there any significant difference in efficiency in using AR to visualize data streaming compared to using 2D displays?
- Does augmented reality visualization improve one's ability to monitor and analyze network traffic patterns?

Null Hypothesis:

- H0-1 – There is no significant difference in efficiency in using AR to visualize data streaming compared to using 2D displays.
- H0-2 – There is no significant improvement in using augmented reality visualization to monitor and analyze network traffic patterns compared to using 2D visualization.

b) Participants: Twenty-two participants (n=22), fourteen (14) male and eight (8) female, with ages equal to or greater than eighteen (18) participated in the experiments. Participants were randomly selected from various majors while participating in classes or laboratories across the university campus. The initial phase was conducted by having users briefly explore experimental devices.

c) Apparatus: The experiments used several laptops and other electronic devices, including the Samsung S2 9.7" 32GB Android Tablet. The main assessments were completed with the Microsoft HoloLens running the Windows Mixed Reality Platform under the Windows 10 Operating System (see Figure 3). Software included selected Universal Windows Platform (UWP) Apps to install and set security configurations, along with Visual and Android Studio 2017 and Unity 2017 for development (Figure 1).

HoloLens System Specifications (concise):

- Operating System: Windows 10.0.11802.1033
- HPU (Holographic Processing Unit): Intel 32-bit Atom x5-Z8100, 1.04 GHz

- Sensors: Inertial Measurement Unit, 4x environment understanding cameras, mixed reality capture, 4x microphones, ambient light sensor
- Display: See-through holographic lenses (waveguides), 2x HD 16:9 light engines, Automatic pupillary distance calibration, 2.3M light points holographic resolution, >2.5k light points per radian; Video Speed: 30 FPS
- Interactions/Understanding: Spatial sound, Gaze tracking, Gesture input, Voice support [1]

Figure 1. An experimental subject wearing the HoloLens, interacting with gesture-based interface.

d) Instruments for Experiments: The experimental instruments included a pre-experiment survey and post-experiment survey. Specific questions that were administered to the participants for each experiment are listed below.

Pre-Experiment Survey (*selected questions*):

1. *How would you rate your current knowledge of AR technology?*
2. *How easy is to use AR technology?*
3. *How do you feel about the usage of AR technology to gather data versus the traditional 2D environment?*
4. *Do you believe data could be easier to comprehend with the usage of AR technology?*
5. *How much difficulty do you believe you would have working with AR technology over using an Android device?*

Post-Experiment Survey (*selected questions*):

1. *How easy was it for you to use the HoloLens?*
2. *To what extent did you comprehend the streaming data shown?*
3. *Do you believe there was a benefit in incorporating AR technology?*
4. *Preference - Augmented Reality 3D display of data versus Traditional 2D display of streaming data.*
5. *For AR display, do you prefer one device to another?*

e) Procedure: In the first phase of this study, a prototype augmented-reality application for the visualization of streamed data of network traffic was designed and developed. Several visualization prototypes were designed and tested using device-specific user interface commands.

The next phase was to measure the effectiveness of the AR system. An experiment was designed and implemented as follows. Twenty-two (n=22) participants explored the model AR visualizations on the HoloLens. They were given pre- and post-experiment surveys to respond. The results were then analyzed and graphed.

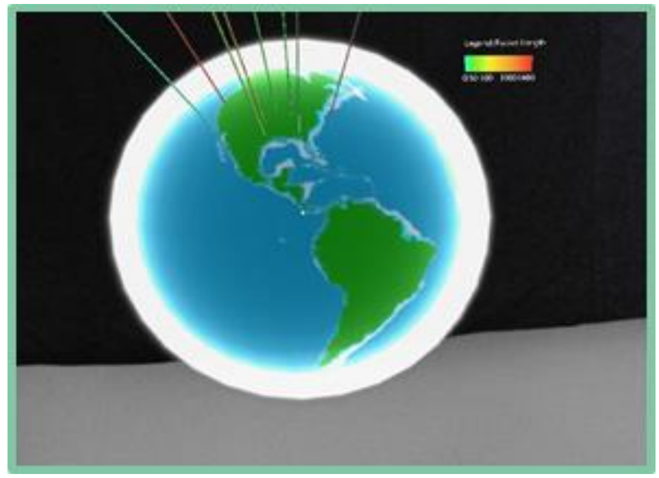

Figure 2. Global visualization (screen snapshot); shows the region packets are coming from, colored by packet length.

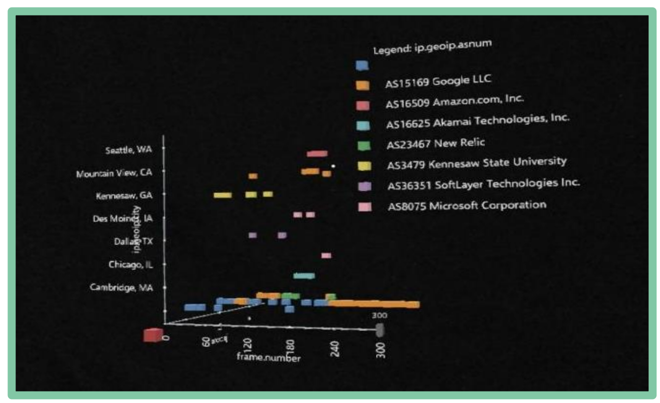

Figure 3. Cube visualization (screen snapshot); shows network data in 3Dimensional graph; the x-axis is the frame number; y-axis, region; and z-axis, IP protocol, colored by AS Number.

Prior to the experiment, participants were first given a brief explanation of what Augmented Reality and the HoloLens were and the data that would be shown to them. The HoloLens head strap was adjusted to fit each participant, and they were shown how to use the air tap gesture in order to make a selection while wearing the HoloLens. The application was open prior to giving the HoloLens to participants. From within the application on the HoloLens, participants could see a selection menu with two options in the form of holographic buttons. The buttons were labeled "Globe" and "Cubes." Using the air tap gesture while the gaze was focused over a button would result in that data visualization being loaded and displayed (See Figures 2 and 3).

After selecting an option, the corresponding visualization would appear in front of the participant in augmented reality. The participant was then free to explore the model from any angle as if it were an object in 3Dimensional space. Focusing their gaze on select markers within the visualization would bring up additional information about the datum. When the participant was finished viewing the model, they were prompted to select the button to return to the main screen, at which point they could select and view the second visualization. After participants had examined both models, they were given the post-experiment survey to respond.

IV. RESULTS AND ANALYSIS

The results showed that participants were largely positive about the benefits of AR technology to visualize streaming big data both before and after experimenting with the model. Participants did report having more difficulty using the HoloLens device than they had anticipated in the pre survey. Results for comprehension of the data displayed ranged from average to strong. In the post survey, a strong majority of participants said they believed there was a benefit in incorporating AR technology in data visualization.

Before analyzing the collected data, participants of the experiment completed a pre-experimental survey. This was conducted in order to obtain information about the participant's general knowledge of Augmented Reality technology and the HoloLens. After experimenting with the application, participants answered similar questions in a post-experiment survey. Results were compared in order to determine any significant difference pre- and post-experiments.

Out of twenty-two participants, a majority of 59% estimated they had a moderate understanding of AR in the pre-experiment survey. 22% of participants reported having little or no understanding of AR. 54% anticipated they would experience a moderate level of difficulty using AR. When asked about their preference in using AR to visualize data versus using traditional 2=D displays in the pre-experiment survey, responses were largely positive with respect to AR, with 45% reporting a strong preference for AR. Participants had similar positive results in the pre-experiment survey in regard to their anticipated comprehension of the data to be shown to them in AR, with 59% anticipating an AR visualization of data to be significantly easier to comprehend.

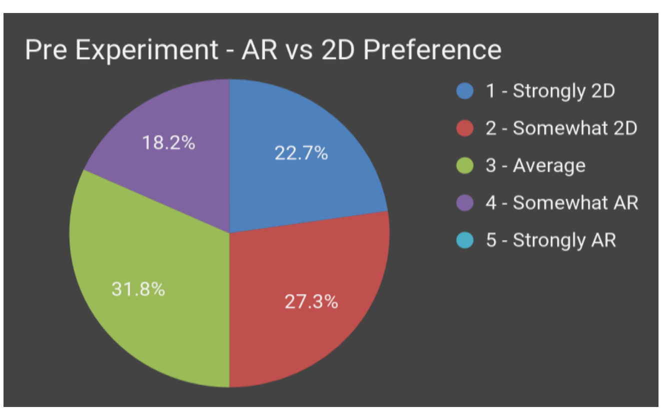

Figure 4. Shows averages for pre-experiment survey question on participants' preference for AR vs 2D display of data.

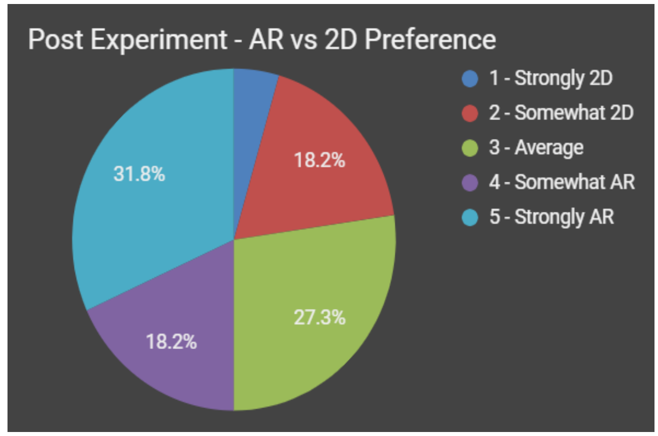

Figure 5. Shows averages for post-experiment survey question on participants' preference for AR vs 2D display of data.

In the post-experiment survey, most participants reported having some difficulty using the HoloLens. 36% reported slight difficulty using the HoloLens, and 31% reported significant difficulty using the device. We observed that most of the participants' difficulty related to forming the HoloLens-specific air tap gesture necessary to select options on the device (Figure 8). When asked about their level of comprehension of the AR data in the post experiment survey, 45% reported a moderate level of comprehension, while 27% reported somewhat high levels of comprehension and 22% reported high levels of comprehension of the data. When participants were questioned about their preference of data visualization in regard to AR vs 2D, results were varied. 27% reported no particular preference, while 18% reported somewhat favoring 2D and 18% reported somewhat favoring AR. 31% reported a strong preference for AR and 4% reported a strong preference for 2D data visualization (See Figures 4, 5, 6 and 7 for detailed responses percentages to selected survey questions.)

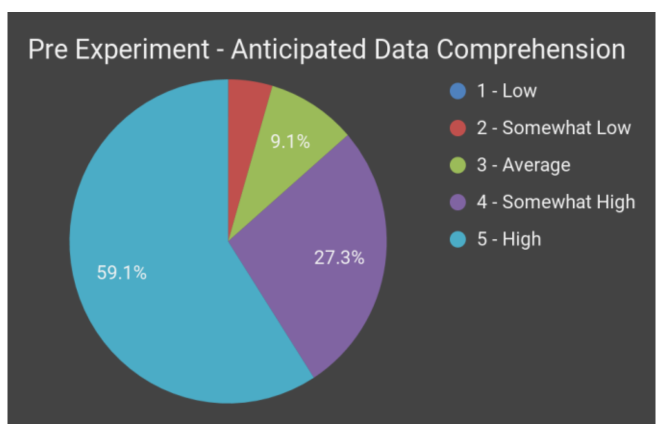

Figure 6. Shows averages for pre-experiment survey question on participants' anticipated comprehension of the data to be displayed.

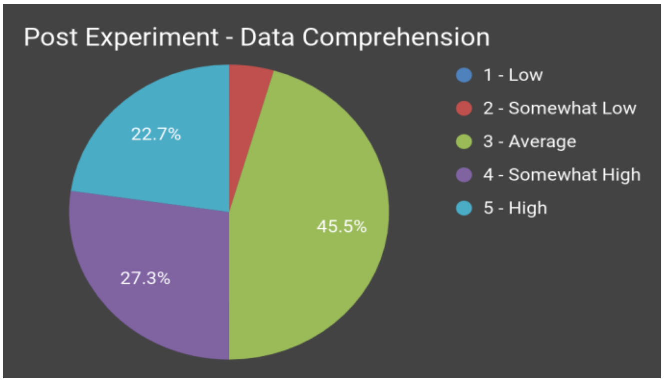

Figure 7. Shows the averages for the participants' comprehension of the data displayed in the AR model.

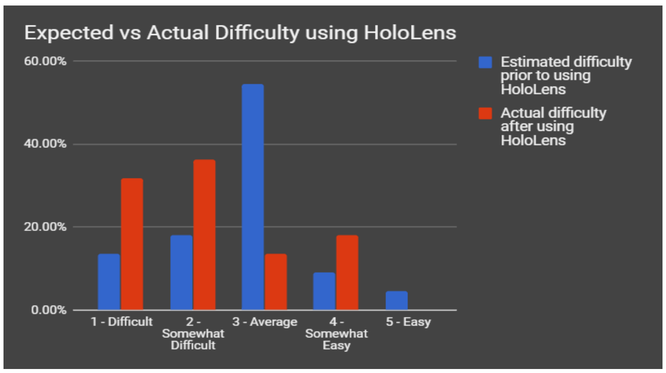

Figure 8. Graph showing averages of participants' expected difficulty using the HoloLens (blue) vs their actual difficulty (red) after using it.

Shown in the tables 1, 2, 3, and 4 below are the results of ANOVA statistical analysis of the participants' responses corresponding to null hypothesis 1 (H0-1) and null hypothesis 2 (H0-2). These were the questions related the participants' expected and actual experience operating the HoloLens and their expected versus actual level of comprehension of the AR data visualizations. For the ANOVA results, if the p-value is < 0.05, we conclude that there is a significant difference between groups and reject the corresponding null hypothesis. For the ANOVA results corresponding to null hypothesis H0-1, the p-value is 0.09 (Tables 1 and 2). We therefore conclude that there is not a significant difference between groups and we do not reject null hypothesis H0-1. The p-value from the ANOVA results corresponding to null hypothesis 2 is 0.0085 (Tables 3 and 4). We conclude that there is a significant difference between groups and therefore reject null hypothesis H0-2.

Null Hypothesis H0-1 - Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
H0-1 Pre	22	60	2.73	0.97
H0-1 Post	22	48	2.18	1.20

Table 1. ANOVA statistical summary of the pre- and post-experiment results corresponding to Hypothesis H0-1.

H0-1 – ANOVA Computations						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit.***
Between Groups	3.27	1	3.27	3.01	0.09	4.07
Within Groups	45.6	42	1.09			
Total	48.9	43				

Table 2. ANOVA statistical analysis of pre- and post- experiment results corresponding to Hypothesis H0-1.

Null Hypothesis H0-2 - Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
H0-2 Pre	22	97	4.41	0.73
H0-2 Post	22	81	3.68	0.8

Table 3. ANOVA statistical summary of the pre- and post-experiment results corresponding to Hypothesis H0-2

H0-2 – ANOVA Computations						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	5.82	1	5.82	7.61	0.0085	4.07
Within Groups	32.09	42	0.76			
Total	37.91	43				

Table 4. ANOVA statistical analysis of pre and post experiment results corresponding to Hypothesis H0-2.

V. CONCLUSIONS & FUTURE RESEARCH

From the ANOVA statistical results, we could not conclude that there was a significant difference between groups of pre- and post-experiment survey responses corresponding to null hypothesis H0-1. We did however find a significant difference in pre- and post-experiment survey responses corresponding to null hypothesis H0-2. This leads us to be unable to conclude that there is a significant difference in efficiency in using AR to visualize data when compared to 2D visualization, but there is an improvement to be had in using AR to monitor and analyze network traffic patterns.

One of the primary difficulties participants encountered was in using the gesture-based interface to select options on the HoloLens. In particular, several participants reported difficulty in using the air tap gesture. As ease of use was one of the metrics used in evaluating null hypothesis H0-1, it is likely this had an impact on the results.

While the primary objective of this research endeavor was to create an innovative pedagogical environment for learners, the purpose of the research component was to develop a prototype application for the HoloLens in AR data visualization. As AR is an emerging field with the HoloLens a developing technology at its forefront, we can assert with confidence that applications in AR data visualization will continue to expand in both scope and utility for personal and professional use. Our hope is that this project demonstrated one such use with the potential to be expanded and enhanced in the future.

In regard to the pedagogical component experiment, preliminary results showed that using augmented reality to visualize network data enhances comprehension of the data; though, the results of this specific experiment seem to be statistically inconclusive. Further research is in progress; however, a positive and extremely exciting pedagogical environment was obviously created. Furthermore, learners' engagement with the experiment was tremendously high. Learners not only learned all the components of applied and state-of-the-art research, such as using high-tech equipment and working with research subjects, they also received a great experience through collaborating with other learners. This research report is a testimony to their successful efforts as undergraduate students in being able to design, develop, implement, document, report and collaborate on this project. One of our immediate future plans is to collect systematic objective and subjective data for detailed analysis of the impact of such a research endeavor, with focus on creation of pedagogical environments to improve learners' accomplishment and attainment.

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