Design and Evaluation of a Learning Assistant System with Optical Head-Mounted Display (OHMD)

Xiao Du Ali Arya
xiaodu@cmail.carleton.ca arya@carleton.ca
School of Information technology, Carleton University
1125 Colonel by Drive, Ottawa, Canada ON K1S 5B6

Abstract. Rapid increase in the use of wearable technologies, especially Optical Head-Mounted Display (OHMD) devices (e.g. Google Glass), suggests potentials for education and requires more scientific studies investigating such potentials. The issue of information access and delivery in classrooms can be of interest where multiple screens and objects of attention exist and can cause distraction, lack of focus and reduced efficiency. This study explores the usability of a single OHMD device, as an alternative to individual and big projection screens in a classroom situation. We developed OHMD-based prototypes that allowed presentation and practice of lesson material through three displays and two control options. We conducted user studies to compare various feasible combinations of display/control mechanism using a series of evaluation criteria, including enjoyment, ability to focus, motivation, perceived efficiency, physical comfort, understandability, and relaxation. Our results suggest that improved OHMD technology will have the potential ability to be effective in classroom learning.

Keywords: Optical head-mounted display, See-through project glass, Enhanced classroom education, User experiment

1 Introduction

Traditional face-to-face education has played a primary role in human cultural heritage and development for thousands of years. Recently, emergence of wearable technologies, particularly Optical Head-Mounted Display (OHMD) devices such as Google Glass, has changed the landscape of computing for the everyday person [13]. Projects like “Mono-glass” [18], Google Glass for assisting in Parkinson’s disease [7], surgeons’ operation assistance [8], “Fitnamo” [10] and “Museum Guide” [15] reflect the practical value of integrating OHMD technology into relevant fields.

This study was originally motivated by existing research on classroom performance [1, 3], observation of classroom learning, and a series of informal interviews with undergraduate students about the factors that could affect their concentration during class. In a typical classroom scenario, students are provided with various visual sources of information. Among them are big screens (projection screen), personal computing devices, and face-to-face interaction with the instructor/presenter. The distraction caused by multi-orientation moving activity (switching attention to various sources) can be one of the sources of reduced effectiveness of the classroom experience. Another issue was the inefficiency caused by switching focus between the portable computer (pc) display and the teacher's projection display.

Based on the problems reported above, we focused on the usability of OHMD in classroom situations. More specifically, we aimed to investigate if the use of a single OHMD device, as an alternative to individual and big screens, can improve the learning process. Considering the need for controlling the content on this single screen, we also investigated the effect of user vs. presenter/instructor control in that process. In both cases, the effects were studied using a series of evaluation criteria such as pleasantness, ability to focus and effectiveness of learning.

Considering the research limitations and the familiarity with the learning content, the researcher chose a Chinese language class (which was easier to design the lecture material for) as the subject for the study. To make the study more pertinent, we focused on higher education students, who are studying at a college level and above.

2 Related Work

Recent products like Google Glass and Oculus Rift are responsible for popularizing the OHMD devices, but similar researches had been developed for a couple of decades. The Land Warrior system [2], developed by the U.S. army over the past decade, includes a heads-up eye display with an augmented reality visual overlay for soldier communication. In 2010, TRAVIS Callisto [19] was made for troubleshooting and training. The Motorola HC1 [4], which was released in 2014, was a fully speech controlled system, but only offering basic applications such as document viewer. Current OHMD based studies are focused in three fields: medical assistance, manufacturing and navigation.

Researchers have utilized OHMD to resolve medical problems for years. For example, to help people who have difficulty with short-range activities due to losing one eye, Toyoura et al. [18] implemented a pilot system called "mono-glass". The system is a wearable device, which has two cameras to capture images and then reconstruct them for the healthy eye. McNaney et al. [7] presented a study on investigating the feasibility of utilizing Google Glass to help people who have Parkinson's Disease (PD). Muensterer et al. [8] explored the possibility of using Google Glass to help surgeons in the operating room. Despite certain drawbacks, such as low battery endurance, data protection, poor audio quality, and long transmission latency, the authors indicated that there are benefits when integrating the device into surgery. Such benefits include: *maintaining attention*, *intuitive interaction, constantly accessing* related information when making decisions, and *real-time external communication* are the positive aspects that doctors reported during existing studies.

Liverani et al. [6] presented a study on utilizing an augmented reality wearable system called a Personal Active Assistant (PAA) (early prototype of OHMD) to improve the overall integration between engineering design and real prototype manufacturing, by providing features such as object recognition and operation instructions. Shen et al. [17] developed an augmented reality (AR) system to support collaborative product design among members of a multi-disciplinary team. Ong and Wang [11] presented a 3D bare-hand interaction in an augmented assembly environment to manipulate and assemble virtual components.

The "museum guide", demonstrated by Schiele et al. [15], used a see-through display. Utilizing the ability of a wearable device to perceive, recognize, and analyze objects and environments from a first-person perspective. Smart Sight, presented by Yang et al. [22], was an intelligent tourist system that made use of multimodal interaction and wireless communication by providing voice command during touring.

With ability to link virtual and real worlds, many researchers have studied utilizing augmented reality technology into education. The AR-Jam books [5] made by the British Broadcasting Corporation (BBC), for instance, combined physical pages and desktop interaction for children. The Augmented Reality Student Card, presented by EI Sayed et al. [14], was designed to help students visualize different learning objects, interact with theories and deal with information in a 3D format. Moreover, Shelton and Hedley [16] presented a paper on using augmented reality for teaching Earth-Sun relationships to undergraduate students.

Nakasugi and Yamauchi designed a wearable system called Past View [9], which helped users acquire historical viewpoints. Osawa and Asai [12] designed a wearable learning support system which was focus on outdoor education. Vallurupalli [20] discussed the feasibility of using Google Glass for medical education. Wu et al. [21] found that Google Glass was able to help simulation-based training exercises without disrupting the learners' experience.

According to the above literature, the following two sets of evaluation criteria had been commonly used by existing projects, particularly in education: usability (comfort, ease of use, enjoyment) and learnability (motivation, attention, relevance, confidence, satisfaction, efficiency).

3 Experiment Design

With the intention of investigating if the use of a single OHMD device, as an alternative to individual and big screens, could improve the learning process, our main objective in this study was to find answers to two research questions; (1) the helpfulness of OHMD in classroom, and (2) identifying a suitable control mechanism for it. With options for various combinations of display or control mechanism, a series of possible scenarios existed in our study. In order to identify the potential issues and effective ways of doing the user study, a pilot study was first conducted.

3.1 Pilot Study

We considered three possible screen options: the OHMD device, projection (or large screen monitor) shared display, and personal computer (or any other common device with personal screen). To control the content on screen, three mechanisms can be considered: the teacher, the student, and a computer. The teacher-controlled method corresponds to a traditional classroom experience. The student-controlled classroom is similar to cases where students receive hand-outs to view while following a lecture or tutorial sessions where they perform actions on a computer following spoken instructions. The machine-controlled option was imagined as a possibility where a timer-based slideshow is used. Theoretically, the scenarios for user experiments should include all the combinations of screen variables (OHMD, PC screen, and projected display) and controller variables (teacher, student, and machine). Additionally, for some cases, it was possible to have more than one visual screen or controller involved in the scenario.

According to the pilot study, we found that the "machine control" scenario (app materials moving forward automatically as time goes) was not appropriate for student learning in a real classroom situation. Based on the pilot study, we decided to narrow down the 3 x 3 study plan and make it into a series of doable scenarios as presented below (Scenario D was machine-controlled and removed from the list):

- Scenario A: single projection display with teacher controlling
- Scenario B: single OHMD with teacher controlling
- Scenario C: single OHMD with student controlling
- Scenario E: projection display with teacher controlling & PC with student controlling
- Scenario F: projection display with teacher controlling & OHMD with student controlling

3.2 Hypotheses

- H1. The participants' responses will vary significantly over scenarios and criteria.
- H2. The evaluation criteria will be more positive in OHMD-based scenarios with student control.
- H3. For specific tasks, participants will prefer the use of OMHD with their own control.

3.3 Data Analysis Plan

We had the same sample group throughout the experiment, and measured the same participants 5 times (5 experimental scenarios). In each scenario, we measured the same usability criteria (enjoyment, motivation, perceived efficiency, understandability, ability to focus, physical comfort, and relaxation).

We conducted a two-way repeated measures ANOVA test to examine H1. Normality of the sample was planned to be assessed by examining histograms of the distributions, and examining the skewness and kurtosis of the distribution. Histograms were to be evaluated for evidence of central tendency and for skewness and kurtosis statistics.

We conducted one-way repeated measures ANOVA with Greenhouse-Geisser correction and Post-hoc tests using the Bonferroni correction to test participants' responses on each criterion among scenarios for testing H2. Since the data was collected by Likert scales questionnaires, non-parametric ordinal methods are more appropriate. So we conducted a Friedman's ANOVA and Wilcoxon signed-rank test with Bonferroni correction for the pairwise comparison to re-examine the results.

These two test method were used because Friedman's ANOVA is the related non-parametric method for repeated ANOVA, and Wilcoxon signed-rank test is the related non-parametric method for paired t-test. Even though the ANOVA test was preferred in presence of multiple variables, we added the Friedman's ANOVA and Wilcoxon sign-rank test as a measure of extra reliability of results.

We planned to collect participants' reactions and feedback towards the exercise tasks' in each experimental scenario results by self-evaluations using the survey for H3.

4 Prototype Implementation

4.1 Hardware

Our prototype uses **Epson Moverio BT-200** [19]. It is a pair of binocular digital glasses that put a micro-projection display in each transparent lens. The goal of this study is to test the applicability, particularly of a wearable device, within a language learning class. For practical purpose, the device should be easy to wear. Epson's OHMD is small and comparatively light. Unlike Google Glass, Epson's OHMD is heavier yet still acceptable.

An Apple **MacBook laptop** was prepared ahead of the experiment. Participants could view and manipulate the app which illustrated the class-related instructions on an Android emulator during the experiment.

An **Acer laptop** was used to maintain the server program, and to run class app demo which projected on the wall.

A **Samsung Galaxy S3** Android phone was used for the teacher to remotely control the content which projected on the Epson Moverio.

A **BENQ W1100 projector** was connected to the Acer laptop, and projected the class app. The content of the display was controlled by the teacher during the experiment.

4.2 Software

Epson Moverio & Mobile Phone App. Epson Moverio was originally designed for two functions: (1) allowing users to view the materials of the lecture either by manual-control or by teacher's control; (2) allowing users to do the exercise-tasks (listening, reading, writing, and speaking exercises) either by manual control or by teacher's control. We designed three modules: "Text", "Practice" and "Communication", for both Epson Moverio and Mobile control app.

The app layouts on the Epson Moverio and the mobile platform were similar. Epson Moverio, which was "Student Side", was manipulated by either participants or teacher using the mobile phone. Samsung app, which was "Teacher Side", monitored students' exercising performance.

Socket Communication Program. We used the android socket protocol to build the communication between OHMD and mobile phone. As soon as the "Student Side" (OHMD) and "Teacher Side" (mobile phone) programs were launched, they created a socket connection to the server independently. Once certain activity was initiated on

“Teacher Side”, a socket stream message was sent to the “Student Side”. Then “Student Side” would do a relative pre-programed activity according to the socket stream message that it read.

Desktop Simulation apps. We used *IntuiFace* (http://www.intuilab.com/) and Android emulator to simulated apps on projection screen and personal computer, respectively.

5 User Study Results

5.1 Participants Demographic Information

15 participants (8 males, 7 females) ranging in age from 18-36 years old participated in the study. Out of 15 participants, 11 indicated they were native English speakers, and 4 were not. Majority of participants came with zero relevant background knowledge: 9 did not have much Chinese learning experience, 2 had half a year learning experience, 2 had one year of learning experience, and 2 had almost 2 years of learning experience. Moreover, 3 subjects reported they had used a Head-Mounted Display before.

On a 7-point Likert scale (1 = very low, 7 = very high), participants generally rated themselves having medium interests level in learning the main subject (M = 4.6, SD = 1.9), the majority of the participants used mobile apps often (M = 5.3, SD = 2.1), and most of them could make themselves concentrate in class (M = 5.1, SD = 1.4).

5.2 In-Study Scale Rating

We used a combination of parametric and non-parametric methods to analyze the data and verify our hypotheses. Our analysis showed that participants did in fact respond differently to changing the control mechanism or students’ viewing-screen, but no significant change was observed in our evaluation criteria based on changing scenarios.

To verify the Hypothesis 1, a 5 x 7 within-subjects ANOVA was conducted on participants’ agreement ratings, with scenarios and usability criteria as factors. An alpha level of 0.05 was used in our data analysis results. Overall, it was observed that scenarios and evaluation criteria did in fact have significant effect on the ratings, which indicates that the participants did change their responses based on variables. This suggests that the responses had a reasonable level of reliability and at least were not the same when variables changed.

To verify the Hypothesis 2, a combination of parametric statistic method (repeated measures ANOVA with a Greenhouse-Geisser correction and post hoc tests using the Bonferroni correction) and non-parametric statistic method (Friedman’s ANOVA and Wilcoxon signed-rank test with Bonferroni correction) were conducted toward the seven evaluation criteria, respectively. We found that only physical comfort ($F = 17.555$, $p < 0.001$) showed a statistical significant difference among five scenarios, and that was not in favour of OHMD. Results summary is given in Table 1 & 2.

These suggested that scenarios in which students wore OHMD for learning (B, C, F) elicited a statistically significant reduction on physical comfort perceptions compared with the scenarios which did not (A and E); but there were no significant difference of physical comfort among the scenarios with OHMD, or between the scenarios without OHMD.

Table 1. Results of Repeated Measures ANOVA with a Greenhouse-Geisser Correction toward Criteria.

Criteria	Scenarios	N	Mean	Std. Deviation	Source	F	Sig.
Enjoyment	Scenario A	15	5.33	1.113	Scenario Greenhouse-Geisser	2.370	0.079
	Scenario B	15	5.13	1.125			
	Scenario C	15	5.67	0.976			
	Scenario E	15	4.67	1.291			
	Scenario F	15	4.73	1.033			
	Total	15	5.11	1.146			
Ability to Focus	Scenario A	15	5.47	1.552	Scenario Greenhouse-Geisser	1.423	0.253
	Scenario B	15	5.20	1.568			
	Scenario C	15	5.20	1.474			
	Scenario E	15	4.73	1.438			
	Scenario F	15	4.53	1.302			
	Total	15	5.03	1.470			
Motivation	Scenario A	15	5.20	1.207	Scenario Greenhouse-Geisser	1.424	0.254
	Scenario B	15	5.53	1.125			
	Scenario C	15	5.87	0.990			
	Scenario E	15	5.20	1.082			
	Scenario F	15	5.27	1.163			
	Total	15	5.41	1.116			
Perceived Efficiency	Scenario A	15	4.93	1.100	Scenario Greenhouse-Geisser	2.123	0.117
	Scenario B	15	4.93	1.163			
	Scenario C	15	5.67	0.816			
	Scenario E	15	4.87	1.642			
	Scenario F	15	4.27	1.751			
	Total	15	4.93	1.379			
Physical Comfort	Scenario A	15	6.27	0.704	Scenario Greenhouse-Geisser	17.555	0.000001
	Scenario B	15	3.67	1.397			
	Scenario C	15	3.80	1.612			
	Scenario E	15	5.87	0.915			
	Scenario F	15	3.67	1.496			
	Total	15	4.65	1.704			
Understandability	Scenario A	15	5.53	1.125	Scenario Greenhouse-Geisser	0.607	0.595
	Scenario B	15	5.73	0.884			
	Scenario C	15	5.87	0.743			
	Scenario E	15	5.87	0.990			
	Scenario F	15	5.53	0.915			
	Total	15	5.71	0.927			
Relaxation	Scenario A	15	5.73	1.163	Scenario Greenhouse-Geisser	4.512	0.011
	Scenario B	15	4.53	1.187			
	Scenario C	15	4.80	1.373			
	Scenario E	15	5.00	1.254			
	Scenario F	15	3.87	1.506			
	Total	15	4.79	1.407			

Table 2. Results of Friedman's ANOVA and Wilcoxon signed-rank test with Bonferroni Correction toward Criteria.

Criteria	N	Chi-Square	df	Asymp.Sig.
Enjoyment	15	8.912	4	0.063
Ability to Focus	15	5.145	4	0.273
Motivation	15	6.070	4	0.194
Perceived Efficiency	15	7.915	4	0.095
Physical Comfort	15	37.790	4	0.00000012
Understandability	15	1.219	4	0.875
Relaxation	15	11.631	4	0.20

5.3 Post Quiz Questions

To verify the Hypothesis 3 and let participants evaluate the learning outcomes among the five scenarios, we designed listening, speaking, writing, and reading exercises based on the lecture materials.

According to results of average perceived difficulty level, helpfulness, comfort and learnability of the tasks in each scenario, we did not a find significant difference in dealing with individual tasks over the 5 scenarios. Some general observations are:

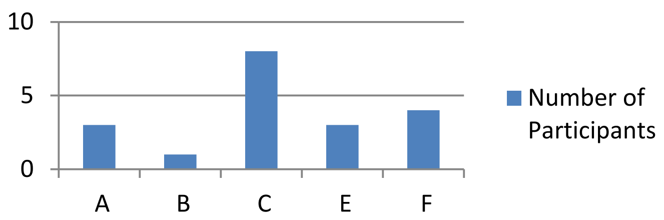
- Educational material and tasks were more suitable for listening and reading as opposed to writing and speaking, regardless of scenarios.
- Student control would result in easier reading.

5.4 Post-Study Feedback

Post-study survey was considered as an extra source of information while the research mainly relied on the analysis of the evaluation criteria. It consisted of only three open questions: (1) overall, was there anything that made you feel uncomfortable during the test? (2) which was your favourite learning scenario? (3) what would you improve about the see-through head-mounted display interaction method for studying?

Question 1. Physical feeling was mostly considered to be the main source of discomfort; and the eye-fatigue caused by wearing the OHMD for too long was another factor that caused unpleasantness for participants. Participants generally reported that looking at two screens was not an enjoyable experience, and they also reported that the virtual screen size and prescription lenses should be customized. Noticeably, providing a notes-taking option by the device was also identified as a potential need.

Question 2. We allowed participants to choose more than one scenario, most participants favoured single OHMD with student controlling. Figure 1 shows the results.



Scenario A: single projection display with teacher controlling

Scenario B: single OHMD with teacher controlling

Scenario C: single OHMD with student controlling

Scenario E: projection display with teacher controlling & PC with student controlling

Scenario F: projection display with teacher controlling & OHMD with student controlling

Fig. 1. Participants' feedback of favoured learning scenario.

Question 3. Participants provided suggestions related to making the OHMD lighter, providing customized vision for individuals, making the virtual screen adjustable, improving the control pad, and using electronic stylus for writing practice.

6 Discussion

While the study did not show a significant difference in participants' evaluation of scenarios based on the given criteria, it did provide valuable insight into the use of OHMD technology in classroom. In particular, the general comments did show that participants overall favoured the OHMD as a single replacement for all screens, and preferred a control system that provides certain level of flexibility and control by students. While this was not enough to positively verify our main hypothesis (H2), it suggests that the OHMD technology has the potential to satisfy the requirements and achieve higher ratings on our evaluation criteria provided some conditions are met. The verification of H2 showed that the only significant difference was in physical comfort, in favour of not using OHMD. This and further inspection of results offer candidates for improving the usability of OHMD, among them the comfort level and more effective control interfaces are the primary items.

Physical Comfort and Technical Difficulties. It was observed that changing the control mechanism while the display variable was constant, did not change the perception of comfort, but with the same control system, OHMD was rated less comfortable than the projection screen. One can expect that this physical discomfort had negative effect on the overall experience and could have resulted in lower ratings of other criteria due to lowered general usability. Eye fatigue in addition to technological issues such as lack of screen size-adjusting and prescription lenses, weight of the device and inconvenient controls which can be resolved in near future are likely to be the cause of OHMD-based scenarios' inability in significantly improving the experience. Improving these issues is very likely to happen in future version of OHMD devices and this will make the technology still an attractive option for research and development in education field. Participants' rating of OHMD for *ability to focus* was not higher than the projection display either, which again could be explained by the difficulties of using OHMD. Moreover, familiarity with more traditional mechanisms and the learning curve associated with new technologies can also have a potential effect on the evaluation, and make the scenarios look equal while the OHMD-based ones could potentially be more effective and helpful.

Motivation and Enjoyment. The participants' motivation and enjoyment ratings were higher than other criteria in the scenario C (single OHMD with student controlling); we did not find a similar pattern in other scenarios. This suggests that most of the participants had positive attitudes toward using OHMD by themselves for educational activities. The results of the post-study survey also verified this suggestion. Considering participants viewed and interacted with the same interface among five experimental scenarios, the reason behind this variance should be due to the novelty of OHMD and students' desire to play with new technology, rather than the design and implementation of class material software. Based on the experimental design and statistics, we could conclude that the novelty of new technology affected the participants' overall responses, but there was no evidence indicating how much novelty affected the results.

Educational Features. Contrary to our assumption, participants' responses to *ability to focus* questions were not the highest when using OHMD. According to the statistical analysis, people generally preferred scenario A (single projection display with teacher controlling) as the most satisfying scenario for concentration when learning. This suggested that participants' *ability to focus* might not only be affected by wearing an "eye-close" virtual screen at all times, but also by who controls the content or interpersonal distractions during a learning procedure. Also we found that the *ability to focus* rating was the lowest in the experimental scenario which involved projection display and OHMD screen. Most of the participants were not comfortable with switching their eye-focus between OHMD screen and teacher's projection display. This indicates that we need further research to figure out a better way for OHMD to improve user's concentration capability.

Other Considerations. Our experimental design was to have participants repeat the same learning material 5 times. Participants may have gotten bored with the tests/materials and stopped caring. So when planning the user study, we made three decisions to minimize the possible negative effects. First, the participants were informed of the experimental procedure and asked to answer the questionnaires according to the related experimental scenarios as objectively as possible. Second, participants completed the five experimental scenarios in randomized order so that potential boredom and fatigue would affect scenarios in an unbiased way. Third, we made the hypothesis H1, and conducted a two-way repeated measure ANOVA to examine participants' responses. The results for H1 verified that participants' responses varied significantly based on changes to the experimental scenarios and evaluation criteria. Therefore, we had enough reason to believe that boredom only had a slight effect on the result.

7 Conclusion

The study presented in this paper developed an OHMD-based prototype and designed a user study in order to investigate the ability of OHMD devices as a single screen in the classroom. The recent availability of wearable sensors especially OHMD devices, provides an alternative that we aimed to explore.

According to the results, there was no significant difference between participants' perceptive responses towards the enjoyment, ability to focus, motivation, perceived efficiency, understandability, and relaxation among the five feasible scenarios. This did not positively support our main hypothesis that OHMD-based approach is preferred but suggested physical comfort as a main issue. Similarly, there was no statistical significant difference between control mechanisms but over various questions participants showed a general interest toward having control over process.

However, participants' feedback showed that they favoured OHMD as a single screen, while their main complaints about it were related to physical comfort and ease of control. Our results are encouraging for the OHMD-based solutions as they show promise that by resolving some issues they can provide a more effective solution in classrooms and replace the need for multiple screens with a single see-through option with multiple control mechanisms. We believe the ergonomic design and hardware will be developed as time goes by, which will make OHMD as comfortable as normal glasses and so improve its overall usability. Although the research findings were not decisive, the lack of support for OHMD can be explained by the technical and setup issues that were discussed above. This suggests that research on usability of OHMD in classroom should continue along with advancing the technology and customized content development.

8 Acknowledgment

This work has been financially supported by Social Sciences and Humanities Research Council of Canada (SSHRC) through IMMERSe Research Network (http://immerse-network.com).

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