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gPhysics – Using Google Glass as Experimental Tool for Wearable-Technology Enhanced Learning in Physics

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Abstract. In this paper we argue that to be viable outside specialized domains (e.g., industrial maintenance) HMDs must be seen as part of a broader concept we refer to as Head-Centered, Context-Aware Computing. Therefore we present a fully functional application prototype gPhysics app which is based on the Google Glass platform and designed to perform an educational physical experiment in the area of acoustics. The initial application is intended for students whose task is to find the relationship between the frequency of the sound generated by hitting a glass of water and the amount of water in the glass. With this experiment, we discuss the possibilities for sensing and interaction in the head/face area. The method described here takes previous research into new directions with the specific features provided by Google Glass. We present a concrete example of our research towards a vision of head-centered computing by discussing a Google Glass app for supporting experiments in physics teacher education training and in high-school physics classes. In a first study discussed in this paper, we focus on the implementation of Google Glass as an experimental tool in undergraduate regular physics teacher education courses. Based on the theoretical framework of the Cognitive Theory of Multimedia Learning (CTML; Mayer, 2005) and the Cognitive Load Theory (CLT; Chandler & Sweller, 1991), we study the variables curiosity and cognitive load in an experimental intervention-control-group design using the nonparametric Mann-Whitney test for independent random samples. The findings indicate that curiosity is indeed affected by the app and device use, while the cognitive load does not differ significantly between the two groups.

Keywords. HMD, Google Glass, Wearable-technology enhanced learning, Physics Education

1. Introduction

While wireless communication and mobile technologies provide opportunities for new interaction approaches, active wearable computing in general (Lukowicz et al., 2006; Ward et al., 2007) as well as mobile and ubiquitous learning in particular (Hwang et al., 2009; Hwang & Tsai, 2010; Rogers et al., 2005; Wu, Hwang & Tsai, 2013) have

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become dynamic and active research areas in recent years which have resulted from the technological development, too.

After Starner (2013) introduced Google Glass to the academic community, research in the field of activity recognition showed that Google Glass provided new ways of improved activity recognition, by detecting and analyzing users' blink frequency (Ishimaru et al., 2014) with its built-in proximity sensor. While using Google Glass as an experimental tool for physics experiments is new, this project relates to an extremely dynamic trend in physics education: using internal sensors of everyday modern communication technology as experimental tools (brief summary: Kuhn, 2014; column for examples on high-school level: Kuhn & Vogt, 2012; implementation in university curriculum: Klein et al., 2015). The method described here takes previous research into new directions by using the specific features of Google Glass. Without adding much obtrusiveness and social awkwardness, we will move from the classical HMD vision with only a near-eye display to novel, elaborate sensing and interaction concepts of head-centered, wearable-technology enhanced learning.

2. Theoretical Background and Rationale

It is well known that competent handling of multiple representations is significant for learning and solving problems – especially in science education (Ainsworth, 1999 & 2006; Dolin, 2007). Furthermore researchers have found that integrating multiple representations (especially visual ones) enhances the conceptual learning environment for many students (Dori & Belcher, 2005; Gilbert & Treagust, 2009; van Someren, Reimann, Boshuizen, & de Jong, 1998).

A psychological model for understanding the cognitive processes while working with multiple representations is offered by the Cognitive Theory of Multimedia Learning (CTML; Mayer, 2005) and the Cognitive Load Theory (CLT; Chandler & Sweller, 1991). Referred to as CTML, the generation of a mental model of learning content requires an active part in information processing. The presentation format of the learning material is essential and can be structured into text / picture or classified according to dynamics and interactivity (Girwidz et al., 2006a; 2006b). Students' learning is improved by presenting text and picture / video instead of learning with text alone. While using the pictorial and verbal channel simultaneously, sensory and representational differentiations are connected and, as a result, cognitive load is reduced (multicoding). Hence, capacity of working memory is available for germane cognitive load in order to form mental representation models according to CTML and, therefore, learnability is increased.

Besides the importance of multiple representations for better learning, it is presumed that curiosity is one of the three pillars of academic performance (von Stumm, Hell & Chamorro-Premuzic, 2011). By Using Google Glass as experimental tool in the way described above, the interaction with this mobile device could provide a new means of exploring scientific phenomena.

In principle all of the above (and other) sensing and interaction modalities could be integrated around an unobtrusive HMD frame, extending the HMD system towards the vision of head-centered, context-aware computing. Using Google Glass as an experimental tool in the way described below (see 3.1 and 3.3) offers the possibility to work actively with different representational formats simultaneously, e.g., line diagram, bar graph, symbols, scale reading. Parallel to the near-eye presentation of multiple representations, students can still conduct the experimental tasks with both hands.

Based on the theoretical framework and the rationale mentioned above, we hypothesize that wearable-technology enhanced learning with Google Glass

- fosters curiosity, motivation, concept learning as well as representational and experimental competencies, and
- reduces cognitive load.

In this first study, we focus on the implementation of Google Glass as an experimental tool in undergraduate regular physics teacher education courses and study the variables curiosity and cognitive load in a first step.

3. Material and Methods

3.1. Experimental Procedure

The core idea is that the students fill the glass with water and test the frequency while, at the same time, Google Glass incrementally generates a graph showing the relationship between fill level and frequency. When water is filled in the water glass, the frequency of the tone lowers. This happens because as water is added more mass is added to the water glass. More mass results in a smaller/lower vibrating frequency, and less mass produces a faster/higher vibrating frequency of the wall of the glass. Noticeably, the phenomenon that students should detect is that the pitch does not correlate linearly with the fill level (see Figure 1.), contrary to what they might have assumed based on their everyday experiences. Until the water glass is nearly half-full, the pitch changes less when a fixed amount of water is added compared to when the water glass is nearly full. Thus the student can view the results on the display as the experiment evolves (while he fills/removes water into/from the glass).

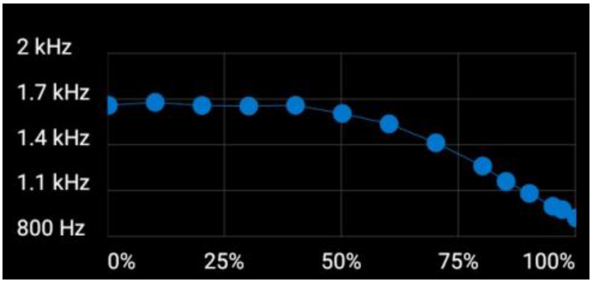

Figure 1. Measuring the relationship between the fill level of a glass of water and the resulting tone example with Google Glass. Screenshot of the gPhysics App after finishing the experimental task.

As shown in Figure 2 the gPhysics app was developed as follows: It first requests input of the fill level, which can be entered by voice, by a head-motion-driven slider (with an eye blink as confirmation) or by automatically using the built-in camera (again with an eye-blink confirmation). The students then access the measurement menu. They hit the glass with the wooden peg and the generated tone is analyzed by the built-in Glass microphone until the app has detected the tone three times with no or only small deviations. The current frequency is added to a diagram displaying the water fill level (x-axis) and frequency (y-axis). The procedure is repeated until the student has recorded enough points to calculate the dependence.

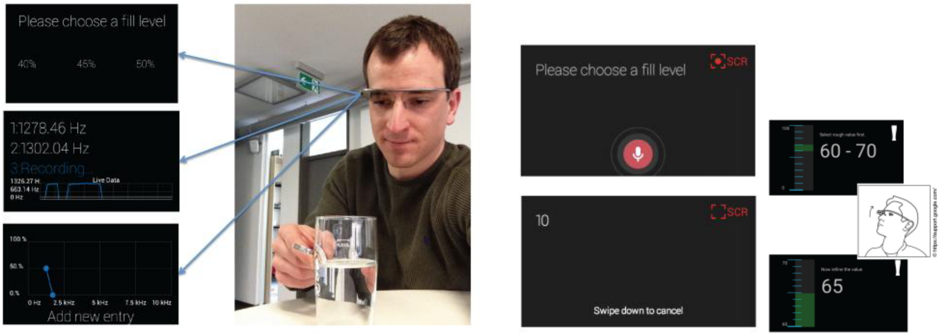

Figure 2. Left: The concept of the gPhysics education app with users inputting the water level in a glass, striking it to generate sound, which the Google Glass device analyzes, and obtaining a real-time plot of the fill level-frequency dependence. Right: Different input modalities are shown: (1) voice input, (2) level input through head inclination with eye blinking for confirmation, and (3) automatic recognition with the Google Glass camera.

We implemented the Google Glass application with the Glass Development Kit (GDK), an add-on of the Android SDK which enabled us to build Glassware running directly on Google Glass (as opposed to Google Glass Mirror API which does not allow full hardware access and interaction). The visualization and input (including eye-blink and head-motion detection) build on the provided routines. The image processing is implemented with OpenCV computer vision libraries and essentially consists of two stages: first, the detection of the fluid color component and, second, the detection of the colored labels and estimation of the filling level. We used a bright green fluid created with green food coloring and five orange stripes with their upper edges aligned with 100%, 75%, 50%, 25%, and 0%. Originally we implemented the entire detection to run on the Glass device. However, together with the sound processing it made the system overheat and we had to transmit the images to an external computer for processing. The resonant frequency detection algorithm is a multi-step pipeline process that forwards the provisional results to the next stage following the subsequent series of steps: reading audio buffer, applying Fast Fourier Transformation, filtering frequencies between 650 Hz and 2000 Hz, detecting frequency with highest magnitude based on power spectrum, validating detected frequency with a magnitude threshold (0.5), detecting sequential ascending, resonant and descending values in window sequence. If a sequence is valid, it computes a resulting frequency value. If a sequence is invalid, it searches for a new valid sequence.

3.2. Study Sample

To study students' cognitive load and curiosity when using Google Glass as experimental tool with the gPhysics app in this context, ten randomly sampled physics teacher students examined the relationship between the fill level and tone frequency equipped with Google Glass (TG: treatment group) while ten other randomly sampled physics teacher students explored the relationship with a tablet PC (CG: control group). Both groups had the same cognitive and motivational pre-conditions as well as the same degree of experience with using mobile devices such as smartphones or tablet PCs as experimental tools (as they had previously attended the same experimental courses).

3.3. Study Design

In both cases (TG and CG) the tone generated by hitting the water glass was detected with the microphone of the mobile device. While the TG students were equipped with Google Glass and the gPhysics app, the CG used iPads and the SpectrumView Plus app (for iOS) as the best comparable case.

Before starting the experiments, the students were shown how to use the mobile devices and their apps separately in each of the groups (duration: 45 minutes). This introduction included a presentation of the relevant functions of the devices and their apps (duration: 15 minutes) followed by a 30-minute period during which the students autonomously measured five given, but different measurement examples.

Table 1. Detailed steps of the experimental procedure of TG and CG

Google Glass group (TG)	Tablet PC group (CG)
1. Fill the glass with an amount of water.	1. Fill the glass with an amount of water.
2. Indicate the water fill level by tip (1st glass) resp. blink (2nd glass)	2. Hit the glass with the wooden peg and record the spectrogram of the tone.
3. You are now in the measuring menu. Hit the glass with the wooden peg until the app has detected the tone three times.	3. Read out the smallest frequency with the highest intensity.
Note: In case of invalid measurement, repeat steps 2 und 3.	4. Fill the measuring value in the given table.
4. In case of valid tone detection, the current frequency is added to a diagram displaying water fill level (x-axis) and frequency (y-axis). Chose the option "Add new entry" and repeat the procedure until 12 frequencies have been correctly detected.	5. Repeat the procedure until 12 frequencies have been detected.
5. Have the displayed graph checked by the instructor.	6. Transfer the value table to the given diagram.
6. Change glass 1 and repeat the procedure with glass 2.	7. Have the plotted graph checked by the instructor.
	8. Change glass 1 and repeat the procedure with glass 2.

After the introduction, the students in both groups individually studied the relationship between the fill level of the glass of water and the resulting tone after hitting two different glasses (see Figure 3). While the overall experimental procedure was identical in both groups, the actions differed in some details because of the handling of the two mobile devices and their apps (see Table 1). An overview of the study design is presented in Table 2.

Table 2. Study Design

Time	Google Glass group (TG)	Tablet PC group (CG)
45'	Introduction to using Google Glass and the gPhysics app	Introduction to using the iPad and the SpectrumView Plus app
45'	Study the fill level-tone frequency relationship with Google Glass	Study the fill level-tone frequency relationship with tablet PC
10'	Post-test: curiosity, cognitive load	

The experimental time required by the students to study the phenomenon for each of the two glasses was recorded individually in each group. After finishing the experimental procedure (studying the phenomenon with two different glasses), we measured curiosity and cognitive load with well-established paper-and-pencil tests (Chandler & Sweller, 1991; Litman & Spielberger, 2003).

Figure 3. Students in our study performing the water glass experiment with Google Glass.

4. Results

Because of the small sample size, we will interpret the descriptive data of the conducted paper-and-pencil tests very conservatively and carefully. Figure 4 shows that the two groups differ in their degree of curiosity state. Students who experimented with Google Glass have a higher degree of curiosity state than students in the CG. Using the nonparametric Mann-Whitney test for independent random samples, we established that these differences are significant and with a large Cohen's d effect size ($p = 0.005$; $d = 1.1$).

However, the Mann-Whitney test showed no significant differences concerning the perceived cognitive load (concerning experimental demand and mobile device handling; $p_{\text{experiment}} = 0.8$; $p_{\text{device}} = 0.2$).

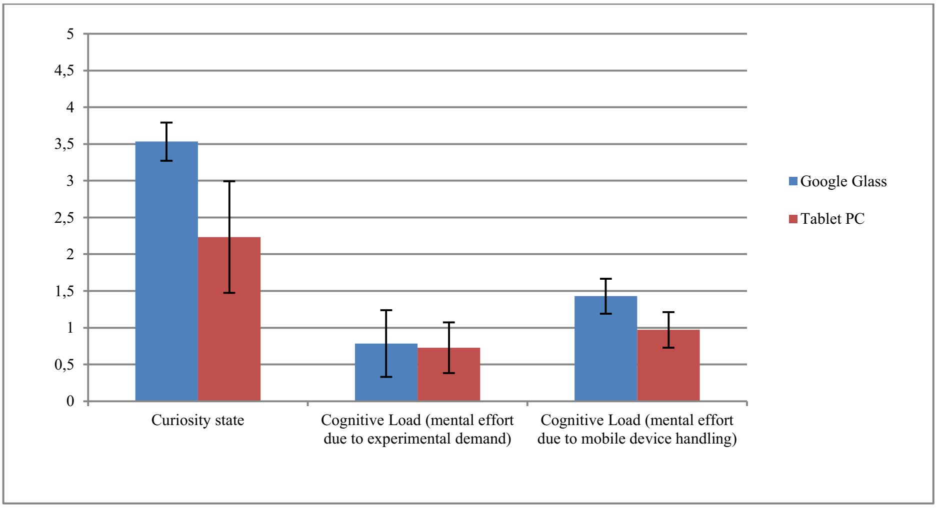

Figure 4. Mean and standard deviation of the curiosity state and the cognitive load of the two groups after experimentation with Google Glass resp. tablet PC (0: small; 5: high).

5. Discussion

The paper reports on a smart glass application and a related experiment that evaluates how cognitive load and curiosity are affected by the use of a digital performance aid when conducting a physics experiment. The findings indicate that curiosity is indeed affected by the app and device use, while the cognitive load is not significantly different from that experienced by the control group working with tablet computers. However, due to the small sample size as well as the special sample and topic, further studies have to be conducted. We are already preparing this topic for high-school students and are planning to expand the content to other topics in physics.

Without adding much obtrusiveness and social awkwardness, we move from classical HMD vision of having only a near-eye display to novel, elaborate sensing and interaction concepts of head-centered, wearable-technology enhanced learning.

In light of progress in miniaturization and sensing technologies, unobtrusive HMD platforms can be extended to tap a broad range of sensing and interaction possibilities associated with the head and face. This will lead to a novel class of context-aware interaction platforms and ultimately make the concept of head-mounted computing viable for everyday consumer use. While today‘s devices such as Google Glass are only beginning to tap this potential, we have shown that they can already be used for novel and interesting applications in educational settings – especially in physics, because of the possibility of using the internal sensors of the HMD such as the microphone. While Google Glass is currently being discontinued, various similar devices are available such as the VUZIX M100 smart glasses or Epson Moverio. A second generation of Google Glass is also said to be in the works.

Therefore we will continue extending our work by using further types of HMD as well as by developing experiments for other topics in science in general and physics in particular.

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