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Exploring User Experience and Media Engagement of Augmented Reality in Product Design Education

Yinghsiu Huang

yinghsiu@mail.nknu.edu.tw

National Kaohsiung Normal University

Research Article

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Abstract

In product design education, it is essential not only to familiarize students with the design process but also to train students how to utilize various forms of design media in different stages. This study aims to teach students how to create and utilize Augmented Reality (AR) within design courses. During the research and analysis phase, a Human-Machine-Environment (HME) analysis is conducted. The Game Engagement Questionnaire (GEQ) was revised for developing a Media Engagement Questionnaire (MEQ) to compare students' perceptions and engagement within traditional PPT and AR-based media in HME analysis. The findings indicate that AR media significantly enhances interactivity compared to traditional PPT presentations with statistically significant. However, producing AR content requires specialized technical skills for students. Although students devoted considerable time and effort to learning AR development for HME analysis, they expressed a strong preference for using AR in design stages.

1. Introduction

The product design process generally consists of four stages: research and analysis, idea generations, prototyping, and development/optimization (Heufler, 2005). In each stage, designers encounter different challenges and utilize various tools and media to convey their design ideas. In design education, students are trained to utilize appropriate media to communicate design problems, user scenarios, concepts, mechanisms, forms, and interfaces…etc. in four design stages. With the advent of computers in the 1970s, computer-aided design, analysis, and manufacturing (CAD/CAE/CAM) have been widely applied in the later stages of product development. These media allow designers to simulate, analyze, and even automate the production of their concepts using digital technologies. In today's design education, students also rely heavily on digital modeling and 3D printing to replace the traditional physical mock-ups. However, during the digital modeling process, students are unable to physically interact with the virtual models, making it difficult to grasp the real scale for forming products. After a time-consuming 3D printing process, students realize the 3D printed model is either too large or too small, or the shape of 3D printed model does not conform well to the ergonomic contours of the hand. Additionally, the materials used in 3D printing are not easily rapid modification by hands. Thus, students must return back to digital models, make revisions, and reprint again. That is a time- and labor-intensive process in which students not only lose the iteration of traditional mock-up making process, but also limit opportunities for design thinking and hands-on forming explorations in the early stage of design process.

With improvements in computation and display technology, Virtual Reality (VR), an extension of computer modeling, now allows designers to evaluate products within an immersive virtual environment prior to physical production. Moreover, Augmented Reality (AR), which has evolved from VR, offers a different approach. While VR constructs entirely virtual environments and objects through 3D computer graphics, immersing users in a digital world and often detaching them from reality (sometimes causing motion sickness), AR attempts to merge virtual models with the real surroundings. With rapidly advancing computer technologies, design education must adapt to these new developments. During

different design stages, the use of various digital design media could support design thinking, facilitate communication, and even enhance the expression of design concepts by unique characteristics of these technologies. Therefore, AR overlays computer-generated models onto real-world environment, which may help address limitations currently faced in design education. For instance, students are used to modeling in virtual software environments, but often relying on time-consuming and labor-intensive 3D printing to validate their designs, physically. AR technology may has the potential to integrate virtual and physical design media, offering new opportunities for more efficient and effective teaching in design education.

Thus, this study attempts to explore how AR can be integrated into the Human-Machine-Environment (HME) analysis phase of product design education, comparing its effectiveness with traditional PowerPoint (PPT)-based media. The research aims to evaluate students' engagement and satisfaction through the implementation of a Media Engagement Questionnaire (MEQ), derived from the Game Engagement Questionnaire (GEQ).

2. Related Works

The early phase of product design is often referred to as the "black box" stage. Historically, computer-aided design (CAD) research has primarily focused on supporting later design stages, emphasizing the presentation and manufacturing of finalized concepts. With the advancement of digital technology, design education must adapt to integrate tools like Augmented Reality (AR) into early-stage conceptual development. By doing so, exploring the integration of AR in the ideation process may offer new insights into design learning and stimulate creativity among students.

To present concepts through AR, designers must first create 3D models and convert them using AR software such as Unity. This process requires advanced modeling skills and adequate hardware to achieve real-time, realistic visualization. However, this technical requirement may limit the spontaneous and intuitive aspects of early-stage design thinking, traditionally facilitated by freehand sketches and physical mock-ups.

Relevant domestic and international studies related to this project can be categorized into two distinct research areas: (1) the development of design media from traditional to digital formats; and (2) theories and related research on VR and AR.

2.1 The Development of Design Media: From Traditional to Digital

With the integration of digital tools into the design process, computer-aided design (CAD) has brought multifaceted impacts on design thinking. In recent years, many studies on creativity have expanded into the field of design computation, exploring the possibility of engaging in creative activities through computational tools (Gero & Maher, 1993; Mitchell, 1993; Boden, 1998). Because computers possess

features superior to traditional media—such as strong computational power, memory capacity, and visual feedback—they are regarded as effective tools for creative engagement and even as a potential source of creative stimulation (Boden, 1998).

By the 1990s, computers were widely recognized as part of the designer's toolkit and began influencing the designer's thought process (Mitchell & McCullough, 1991). Researchers increasingly examined the roles computers play in design and their potential future developments, particularly in assisting the design process (Elsas & Vergeest, 1998). Sasada (1999) pointed out that computers can serve as a powerful medium in design, and categorized their use into three levels. Initially, computers were seen as tools for representation, which were time-consuming to use and offered limited support for design decision-making. Later, they became development media, assisting with communication, evaluation, and presentation to support design decisions. More recently, computers have evolved to assist the early conceptual stage, offering design ideas that could not be generated without computational support, thereby moving closer to the core of design thinking.

Additionally, in their research on Computer-Aided Conceptual Design (CACD), Elsas and Vergeest (1998) identified several advantages of using CAD tools in early design stages: (1) enhancing the quality of design concepts, (2) enabling rapid generation of alternative solutions, (3) providing a better platform for communication and evaluation, and (4) reducing the risk of costly mistakes resulting from early design decisions. Most of these studies have focused on developing computer systems that create a computational sketching environment, enabling designers to test ideas more extensively during the ideation phase (Gross, 1996; van Dijk, 1995; Elsas & Vergeest, 1998).

2.2 Theories and Research on VR and AR

Once digital models of product design concepts are developed, virtual simulation is often used to preview these concepts before mass production. This process, known as Virtual Reality (VR), allows users to enter a digitally constructed 3D space to browse, move freely, or interact with virtual objects. As early as 2003, Burdea and Coiffet identified three defining characteristics of VR (Burdea & Coiffet, 2003):

1. Immersion: Users are immersed in a virtual world generated by computer graphics, simulated imagery, and sound. When distractions are eliminated, users can experience a deep sense of presence in the virtual environment.
2. Imagination: The simulation of imagery, sound, lighting, and texture evokes imaginative responses in users, allowing them to perceive a world that transcends the physical limitations of reality—such as flying through space, walking underwater, or traveling through time.
3. Interaction: Refers to the interface between the user and the virtual space, including real-time changes in angles, lighting, and distance in response to user input through headsets, handheld devices, or full-body motion sensors.

Moreover, derived from VR, Augmented Reality (AR) overlays virtual images and models on real-world views through smartphones, tablets, or head-mounted displays. Although the concept of AR was

proposed as early as 1901 by L. Frank Baum, it was not until the 1990s that it became formally recognized as a technology. As the computing power improved portable devices, AR began a broader application, and became more mature after 2010. Broadly speaking, AR refers to any system that provides supplementary text or image information within a real-world context. For example, an explanatory panel beside an artwork in a museum enhances the viewer's understanding of the piece and thus qualifies as a broad form of AR. Recent examples include Instagram and TikTok face filters, which use camera positioning and algorithms to overlay digital effects in real time—a common use of AR in daily life. On contrast, more technical definition of AR involves the real-time overlay of virtual data onto the physical environment. One example is the Head-Up Display (HUD) in vehicles, which projects real-time information such as speed and fuel levels onto the windshield, reducing the need for the driver to look away from the road. Another example is the AR headset, such as Google Glass (Fig. 1), that superimposes virtual content onto the wearer's field of view.

Nowadays, AR technology is widely used across various domains including education, industry, business, and daily life. Traditional AR systems relied on physical markers and complex development kits, which were time-consuming and expensive. More recently, platforms like MakAR (Fig. 2, left) have enabled easier AR content creation through drag-and-drop interfaces, allowing artists and creators to design interactive AR cards without any coding skills (Lin, 2017). Similarly, Facebook's Spark AR Studio lets users apply 3D models like virtual glasses onto faces in real time and publish their creations directly on social media (Fig. 2, right).

However, relatively few studies have focused on how to teach students to use Augmented Reality (AR) as a design medium during different stages of the product design process. There is also a lack of comparative analysis between traditional media and AR in terms of students' effectiveness in presenting design training content in first phase of design stage, Human-Machine-Environment (HME) analysis.

3. The structure and process of experiment

According to Heufler (2005), the product design process can be divided into four stages: research and analysis, ideation, prototyping, and development/optimization. In each stage, designers encounter different design problems and present their ideas by using various media and modeling methods. In first stage of design education, research and analysis, teacher is teaching students how to conduct Human-Machine-Environment (HME) analysis by using text, images, or videos. Students learn to investigate a real Target Audience (TA) by recording and analyzing their needs, usage scenarios, and problems, and then attempt to propose new functions of ideations to solve TA's issues.

This research did not involve human experiments and therefore did not require approval from an institutional review board. At the beginning of the semester, a detailed syllabus was provided, and the course content and procedures were explained to students prior to the course add/drop deadline. Students who disagreed with the course requirements had the option to withdraw. By remaining enrolled, students consented to the course procedures and the administration of the Media Engagement

Questionnaire. Moreover, in the AR-integrated design course, students anonymously completed the MEQ. The anonymity of responses ensured that the identity of individual students could not be determined, and participation did not affect course grades. Therefore, signed consent forms could not be obtained. “Human Ethics and Consent to Participate declarations: not applicable”.

In this study, a revised version of the Game Engagement Questionnaire (GEQ) was used, named the Media Engagement Questionnaire (MEQ), to compare students' experiences when using traditional PowerPoint (PPT) presentations versus Augmented Reality (AR) applications to conduct and present HME analysis. The MEQ helps assess students’ self-perceived engagement and satisfaction with the media used during this stage of design learning.

3.1 Media Engagement Questionnaire (MEQ) Design

Although students work on the same design topic during class, they may use different media to analyze and present their works. As a result, it is difficult to use a single assessment method to evaluate their learning outcomes or analytical performance. In design education, students experience the design ideation process through different types of media. Thus, their subjective perceptions of whether a medium effectively conveys their ideas can be different.

This study treats the use of design media at the stage of HME analysis as analogous to the engagement in gameplay. Therefore, this research adopts the Game Engagement Questionnaire (GEQ) proposed by Lin (2017), which includes 19 items (Table 1) on a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree). The GEQ was revised into the Media Engagement Questionnaire (MEQ) for assessing students’ engagement with different media during HME analysis. Students completed the MEQ (Table 2), includes 24 items on a 5-point scale, ranging from 1 (strongly disagree) to 5 (strongly agree), for each media type after completing both traditional PPT and AR HME analysis. Thus, these results were then used for statistical analysis.

Table 1
Game Engagement Questionnaire (GEQ)

1	**Questions**
	I lost track of time
2	Things felt like they happened naturally.
3	I felt different from usual
4	I felt scared.
5	The game felt like real life
6	If someone called me during the game, I wouldn’t hear them.
7	I felt extremely excited
8	Time seemed to stop while I was playing
9	My entire attention was focused on the game
10	I couldn’t respond when someone talked to me
11	I couldn’t tell whether I was tired
12	Playing the game became a habit
13	My thoughts were racing
14	I couldn’t focus on where I physically was.
15	I didn’t have to think much about how to play the game
16	Playing the game helped me calm down
17	I played longer than I had expected
18	I was truly immersed in the game
19	I felt like I couldn’t stop playing

Poels et al. (2007) identified 7 dimensions in the original GEQ: immersion, flow, competence, tension, challenge, positive affect, and negative affect. This study reorganized these into 5 core dimensions and added one for media feedback, as shown in Table 2.

Table 2
6 dimensions of Media Engagement Questionnaire

Dimensions	Questions
a. immersion	a1. I was fully immersed in the HME analysis. a2. I thought about other things while doing the HME analysis. a3. When making the PPT/AR HME analysis, I forgot about everything else. a4. I could clearly understand others' HME analysis presented in PPT/AR.
b. flow	b1. I felt a sense of achievement using PPT/AR. b2. I completed the PPT/AR HME analysis quickly. b3. I lost track of time while making the PPT/AR. b4. I was highly focused on my PPT/AR HME analysis.
c. competence	c1. I was satisfied with my PPT/AR HME analysis. c2. I could perform better HME analysis using PPT/AR. c3. I felt I could explore more design problems using PPT/AR. c4. I put a lot of effort into making the PPT/AR.
d. positive effect	d1. I was interested in doing HME analysis. d2. I found the HME analysis using PPT/AR to be challenging. d3. Doing HME analysis with PPT/AR was a rich experience. d4. I felt that HME analysis with PPT/AR could be creative.
e. negative affect	e1. Doing HME analysis made me feel down. e2. I felt bored using PPT/AR for analysis. e3. I felt frustrated using PPT/AR. e4. Analyzing HME with PPT/AR made me feel stressed.
f. feedback	r1. I fully understood others' PPT/AR HME analysis. r2. I enjoyed the process of making the PPT/AR analysis. r3. I felt that I did a good job with my PPT/AR analysis. r4. I felt that I successfully presented the user problems through PPT/AR.

3.2 Design Topic and Experimental Procedure

The design topic selected in this study is a hairdryer, chosen not only for its external appearance, but also for its internal mechanical structure, which plays a crucial role in functionality. While appearance enhances aesthetics, different contexts of Target Audiences (TA) require different forms, such as portable travel models or wall-mounted designs. The goal of this design topic was for students to physically disassemble a hairdryer to understand its internal structure, functional components, and working principles. This experience served as a foundation for redefining the Human-Machine-Environment (HME) relationship and for generating new design concepts.

This experiment was conducted in a junior-level product design studio. Students were required to select a specific TA, such as the elderly, preschool children, or backpackers, and then conduct an HME analysis for that group using traditional media (PPT). Afterward, students were taught how to use AR software to integrate various media, including:

- Text and narration (Fig. 3, left)
- Transparent-background images (Fig. 3, middle)
- Videos (Fig. 3, right)

They then used these to create and present their AR-based HME analysis. This allowed them to creatively combine traditional and digital media in a step-by-step analytical presentation.

Experiment Steps:

Step 1: Students conducted a traditional HME analysis of the hairdryer using PPT slides based on the needs of TA.

Step 2: Students received instruction on AR software and learned to integrate text, narration, photos, transparent images, videos, and audio to build an AR-based HME analysis. Two weeks later, they presented HME analysis by Spark AR Studio.

Step 3: Students completed MEQ surveys comparing their experiences between PPT and AR media.

4. MEQ Data Collection and Analysis

The purpose of this study is to evaluate students' perceived satisfaction when using traditional and AR-based design media during product design education, specifically in the Human-Machine-Environment (HME) analysis stage. This was conducted by using the Media Engagement Questionnaire (MEQ). In a junior-level product design course, students worked on the topic of hairdryers, performing HME analysis during the design analysis stage.

They were asked to complete the MEQ after using both traditional PPT presentations and AR-based tools. In addition, 8 Likert-scale questions were included in the survey to compare students' impressions of the media content characteristics between PPT and AR for presenting HEM analysis. Data was collected through three rounds of surveys, summarized in Table 3.

Table 3
3 data from experiments

Instrument Type	PPT (A)	AR (B)	Media content(C)
HME analysis	A (MEQ)	B (MEQ)	C (Likert)

In this course, AR was experimentally integrated into various stages of the design curriculum. Each class consisted of approximately 40 students. After removing invalid responses, more than 30 valid responses were collected per questionnaire, which met the minimum requirement for statistical analysis. To examine the research questions, the following analyses were conducted:

1. Reliability analysis of three surveys;
2. Two single sample *t*-tests of MEQ scores of traditional PPT (A) and AR (B), respectively;
3. A paired-sample *t*-test to identify significant differences between corresponding items in PPT (A) and AR (B) media;
4. A single sample *t*-test to analyze the media content characteristics comparison (C).

4.1 Reliability Analysis

Reliability analysis included both inter-rater reliability (via Pearson correlation) and internal consistency (via Cronbach's alpha). Recent researches shows that Cronbach's alpha values between 0.50–0.70 indicate basic reliability, while values above 0.70 are considered academically acceptable. De Vellis (1991) also suggested 0.70 as the minimum threshold for acceptable reliability. As shown in Table 4, the MEQ results from both the traditional media (A) and AR media (B) demonstrated strong internal consistency, with Cronbach's alpha values of 0.856 and 0.865, respectively. The media content comparison scale (C) also reached an acceptable level at 0.701.

Table 4
Cronbach's α of 3 data from experiments

Instrument Type	PPT (A)	AR (B)	Media content(C)
HME analysis	A (MEQ)	B (MEQ)	C (Likert)
Cronbach's alpha	0.856	0. 865	0.701

4.2 Two single sample t-tests of MEQ scores

During the design analysis phase, students first conducted an HME analysis using conventional PPT presentations and subsequently completed the first round of the MEQ. Three weeks later, an adjusted HME analysis was presented through AR media, followed by the completion of a second MEQ. In order to evaluate differences in student experience, two single-sample t-tests were performed on each MEQ item in both the PPT and AR media, with the test value at 3 on the Likert scale. The results of the MEQ for the PPT condition are presented in Table 5, while those for the AR condition are presented in Table 6, respectively.

Table 5
Single-sample t-tests of HME analysis in PPT (testing value = 3)

MEQ	t	df	difference 2-tails p	Std Dev	Lower 95% Mean	Upper 95% Mean
a1	-2.044	30	.050	− .38710	− .7739	− .0003
a2	-3.593*	30	.001	− .80645	-1.2648	− .3481
a3	-4.947**	30	< .001	-1.00000	-1.4128	− .5872
a4	− .414	30	.682	− .09677	− .5737	.3801
b1	-2.725*	30	.011	− .54839	− .9595	− .1373
b2	− .284	30	.778	− .06452	− .5279	.3988
b3	-4.636**	30	< .001	− .93548	-1.3476	− .5234
b4	− .147	30	.884	− .03226	− .4813	.4168
c1	− .403	30	.690	− .06452	− .3917	.2627
c2	1.126	30	.269	.22581	− .1839	.6355
c3	.611	30	.546	.12903	− .3023	.5604
c4	.183	30	.856	.03226	− .3282	.3927
d1	-2.231*	30	.033	− .48387	− .9268	− .0410
d2	-1.668	30	.106	− .32258	− .7175	.0723
d3	− .162	30	.873	− .03226	− .4394	.3749
d4	1.097	30	.281	.22581	− .1947	.6463
e1	-3.758**	30	< .001	− .80645	-1.2448	− .3681
e2	-2.436*	30	.021	− .51613	− .9488	− .0835
e3	-4.094**	30	< .001	− .64516	− .9670	− .3233
e4	-2.970*	30	.006	− .58065	− .9799	− .1814
r1	-1.836	30	.076	− .38710	− .8178	.0436
r2	-3.609*	30	.001	− .67742	-1.0608	− .2940
r3	-1.000	30	.325	− .19355	− .5888	.2017
r4	-2.133*	30	.041	− .45161	− .8840	− .0193

** shows p < .001, and * shows p < .05 significant difference.

Following the strength of t values of each MEQ in traditional PPT, there are 4 items, a3, b3, e3, and e1, reaching $p < .001$ significance. For item a3 (“While making the PPT HME analysis, I forgot about everything else”), the t-value was significantly negative at -4.947 ($p < .001$), indicating that students were not fully focused on the HME analysis and were likely multitasking during the assignment. Similarly, item b3 (“I lost track of time while making the PPT”) also had a significantly negative t-value of -4.636 ($p < .001$), suggesting that students were not so focused in the design task. In addition, item e3 (“I felt frustrated using PPT”) yielded a negative t-value of -4.094 ($p < .001$), indicating that students are not frustrated with traditional PPT media because they were already familiar with PPT. Furthermore, item e1 (“Doing HME analysis made me feel down”) also had a negative t-value of -3.758 ($p < 0.001$), suggesting that using PPT for HME analysis did not negatively affect students' mood—in other words, they generally felt okay while completing the task.

Table 6
Single-sample t-tests of HME analysis in AR (testing value = 3)

a1	t	df	difference	Std Dev	Lower	Upper 95% Mean
			2-tails p		95% Mean	
	− .643	**30**	**.525**	**− .12903**	**− .5390**	**.2810**
a2	-2.466	30	.020	− .58065	-1.0615	− .0998
a3	-2.607	30	.014	− .67742	-1.2080	− .1468
a4	-1.273	30	.213	− .29032	− .7562	.1755
b1	− .284	29	.778	− .06667	− .5464	.4131
b2	-3.926**	30	< .001	− .70968	-1.0788	− .3405
b3	-2.129	30	.042	− .54839	-1.0743	− .0224
b4	.432	30	.669	.09677	− .3609	.5545
c1	-1.184	30	.246	− .19355	− .5273	.1402
c2	.626	30	.536	.12903	− .2918	.5498
c3	1.429	30	.163	.29032	− .1246	.7052
c4	3.946**	30	< .001	.80645	.3891	1.2238
d1	-1.201	30	.239	− .29032	− .7842	.2036
d2	5.275**	30	< .001	1.06452	.6524	1.4766
d3	2.899	30	.007	.67742	.2002	1.1546
d4	4.611**	30	< .001	.96774	.5391	1.3964
e1	− .115	30	.909	− .03226	− .6043	.5398
e2	-5.839**	30	< .001	− .93548	-1.2627	− .6083
e3	3.143	30	.004	.61290	.2147	1.0111
e4	1.262	30	.217	.32258	− .1995	.8447
r1	-3.058	30	.005	− .61290	-1.0222	− .2036
r2	-2.244	30	.032	− .45161	− .8627	− .0405
r3	-2.344	30	.026	− .38710	− .7243	− .0499
r4	-3.803**	30	< .001	− .70968	-1.0908	− .3286

** shows $p < 0.001$, and * shows $p < 0.05$ significant difference.

Following the strength of t values of each MEQ in AR, there are 6 items, e2, d2, d4, c4, b2, and r4, reaching $p < .001$ significance. The item with the strongest t-value was e2 (“I felt bored using AR to conduct the analysis”), which had a significantly negative t-value of -5.839 ($p < 0.001$). This indicates that students did not feel bored at all when using AR to present HME analysis. Moreover, the second highest t-value was for d2 (“I found the HME analysis using AR to be challenging”), with a t-value of 5.275 ($p < 0.001$), suggesting that students perceived the AR-based task as highly challenging. Similarly, d4 (“I felt that HME analysis with AR could be creative”) had a significantly positive t-value of 4.611 ($p < 0.001$), indicating that students saw AR as a medium that encouraged creativity.

Students also reported exerting considerable effort in their AR-based projects. For c4 (“I put a lot of effort into making the AR”), the t-value was 3.946 ($p < 0.001$), demonstrating a significant perception of high effort. On the other hand, b2 (“I completed the AR HME analysis quickly”) had a significantly negative t-value of -3.926 ($p < 0.001$), suggesting that students took longer time to complete AR HME assignments due to the learning curve and complexity of the AR software. Interestingly, r4 (“I felt that I successfully presented the user problems through AR”) also had a significantly negative t-value of -3.803 ($p < 0.001$). This may indicate that although students invested substantial time and effort into developing their AR presentations, they were not confident in whether the AR medium could effectively communicate actual user issues, possibly due to their lack of prior experience with AR tools.

In MEQ results of traditional PPT-based HME analysis, most students—being in their third year—had already used PPT many times for similar assignments or presentations. The single-sample t-test results (with significance at $p < 0.001$) indicate that students were highly familiar with this medium. Thus, they were not fully focused on the HME task alone and tended to multitask during the activity. For these students, the traditional PPT media did not offer a novel experience, nor did they find the process particularly enjoyable. In contrast, the MEQ results of AR-based HME analysis show that students regarded AR as a new challenge. They did not find the experience boring, but it required significantly more effort and time to learn and implement. Since most students were using AR tools for the first time, they were unsure whether their efforts successfully conveyed the actual user issues of design requirement.

The MEQ results for the two media types reflect distinctly different tendencies. Therefore, in the following section, a paired-sample *t*-test will be used to further examine whether these differences between PPT and AR media in HME analysis are statistically significant.

4.3 A paired-sample *t*-test

In this subsection, a paired-sample *t*-test was conducted to compare students' responses to the MEQ for traditional PPT and AR-based HME analyses. The results are shown in Table 7. Column A (PPT) presents t-values from the traditional PPT MEQ, while column B (AR) shows t-values from AR-based MEQ. The shaded column displays the results of paired-sample *t*-test, including t-values and the two-tailed significance levels (** indicating $p < .001$).

Table 7
a paired-sample *t*-test of MEQ

MEQ	A(PPT)	B(AR)	paired t	2-tails p
a1. I was fully immersed in the HME analysis.	-2.044	− .643	-1.545	.133
a2. I thought about other things while doing the HME analysis.	-3.593**	-2.466	-1.880	.070
a3. When making the PPT/AR HME analysis, I forgot about everything else.	-4.947**	-2.607	-2.270*	.031
a4. I could clearly understand others' HME analysis presented in PPT/AR.	− .414	-1.273	.924	.363
b1. I felt a sense of achievement using PPT/AR.	-2.725	− .284	-2.289*	.030
b2. I completed the PPT/AR HME analysis quickly.	− .284	-3.926**	2.752*	.010
b3. I lost track of time while making the PPT/AR.	-4.636**	-2.129	-2.555*	.016
b4. I was highly focused on my PPT/AR HME analysis.	− .147	.432	− .812	.423
c1. I was satisfied with my PPT/AR HME analysis.	− .403	-1.184	.680	.502
c2. I could perform better HME analysis using PPT/AR.	1.126	.626	.474	.639
c3. I felt I could explore more design problems using PPT/AR.	.611	1.429	− .961	.344
c4. I put a lot of effort into making the PPT/AR.	.183	3.946**	-3.760**	< .001
d1. I was interested in doing HME analysis.	-2.231	-1.201	-1.235	.226
d2. I found the HME analysis using PPT/AR to be challenging.	-1.668	5.275**	-8.401**	< .001
d3. Doing HME analysis with PPT/AR was a rich experience.	− .162	2.899	-2.935*	.006
d4. I felt that HME analysis with PPT/AR could be creative.	1.097	4.611**	-3.025*	.005
e1. Doing HME analysis made me feel down.	-3.758**	− .115	-3.760**	< .001
e2. I felt bored using PPT/AR for analysis.	-2.436	-5.839**	2.145*	.040
e3. I felt frustrated using PPT/AR.	-4.094**	3.143	-8.593**	< .001
e4. Analyzing HME with PPT/AR made me feel stressed.	-2.970	1.262	-6.053**	< .001
r1. I fully understood others' PPT/AR HME analysis.	-1.836	-3.058	1.488	.147
r2. I enjoyed the process of making the PPT/AR analysis.	-3.609**	-2.244	-1.488	.147
r3. I felt that I did a good job with my PPT/AR analysis.				

MEQ	A(PPT)	B(AR)	paired t	2-tails p
r4. I felt that I successfully presented the user problems through PPT/AR.	-1.000	-2.344	1.235	.226
	-2.133	-3.803**	1.609	.118

** shows p < 0.001, and * shows p < 0.05 significant difference.

Following the strength of t values of a paired-sample *t*-test for comparing traditional PPT and AR media, there are 5 items, e3, d2, e4, c4, and e1, reaching p < .001 significance, and they are also underlined in Table 7. The item with the highest significance was e3 ("I felt frustrated using PPT/AR"), which had a strongly negative t-value of -8.593 (p < 0.001). For this item, t-value in the PPT media was − 4.094**, while in the AR media t-value was 3.143. This suggests that students felt significantly more frustrated when using AR to present their HME analysis compared to PPT. The results imply that students, encountering AR media for the first time, found it unfamiliar and more difficult to manage.

The second highest t-value was d2 ("I found the HME analysis using PPT/AR to be challenging"), with a paired-sample t-value of -8.401 (p < 0.001). In the earlier single-sample t-tests, the t-value for the traditional PPT media was − 1.668 (not statistically significant), while the AR media yielded a significant positive t-value of 5.275 (p < 0.001). This indicates that students were already used to conducting HME analysis with PPT, whereas the AR media presented a new and challenging experience, resulting in a statistically significant difference.

The third highest t-value was e4 ("Analyzing HME with PPT/AR made me feel stressed"). In the earlier single-sample t-tests, t-value for traditional PPT media was − 2.970, and for the AR media, t-value was 1.262. Nevertheless, the paired-sample t-test between the two media showed a significant difference, with a t-value of -6.053 (p < 0.001). This suggests that students felt no stress at all when using traditional PPT for HME analysis. While AR also did not cause substantial stress on its own, the comparison between the two media revealed a statistically significant difference, indicating that students perceived relatively more pressure when working with AR.

Another item showing a significant difference in the paired-sample t-test was c4 ("I put a lot of effort into making the PPT/AR"), with a t-value of -3.760 (p < 0.001). In the earlier single-sample t-tests, the t-value for traditional PPT media was 0.183 (not significant), while the AR media yielded a significant t-value of 3.946 (p < 0.001). This indicates that students clearly invested more effort when creating their HME analysis using AR compared to the traditional PPT media. Finally, the 5th item showing a significant difference in the paired-sample t-test was e1 ("Doing HME analysis made me feel down"), with a t-value of -3.760 (p < 0.001). However, in the earlier single-sample t-tests, the t-value for traditional PPT media was − 3.758 (p < 0.001, statistically significant), while the t-value for the AR media was − 0.115 (not significant in Single-sample t-tests of HME analysis in AR). This suggests that although students reported exerting more effort in the AR-based analysis (as seen item c4), it did not negatively affect their

mood. It is possible that students were receptive to using the new AR media despite the additional time and effort it required compared to PPT, and this effort did not result in emotional discomfort.

4.4 Comparative media content of traditional PPT and AR

This subsection analyzes the media content characteristics used in the HME analysis, including aspects such as text presentation, 2.5D images, video, and interactivity. The questionnaire employed 7-point Likert-scale questions, where traditional PPT was anchored on the left-hand side of the scale and AR media on the right-hand side. The closer a response was to the left, the more effective the item was perceived to be when using PPT; conversely, the closer to the right, the more effective it was perceived when using AR. The results of the one-sample t-test analysis (testing value = 4) is presented in Table 8.

Table 8
traditional PPT and AR media content comparation

Content of media	**t**	**df**	**2-tails p**
C1. Which medium provides better text presentation?	-2.962*	30	.006
C2. Which is better for presenting 2.5D images?	5.791**	30	< .001
C3. Which is better for presenting video (PPT or AR)?	-3.574*	30	.001
C4. Which medium, PPT or AR, offers better interactivity?	14.709**	30	< .001
C5. Which medium requires more professional production skills?	12.243**	30	< .001
C6. If there were no technical barriers, I would prefer to use PPT/AR	2.066*	30	.048
C7. If I were the audience, I would like to watch a presentation using PPT/AR	.800	30	.430
C8. I think PPT/AR can help people better understand HME analysis.	− .385	30	.703
** shows p < 0.001, and * shows p < 0.05 significant difference			

In terms of the PPT and AR media content comparation, there are 3 items, C4, C5, and C2, reaching p < .001 significance, and they are also underlined in Table 8. The item with the highest t-value was C4 (“Which medium—PPT or AR—offers better interactivity?”), with a t-value of 14.709 (p < 0.001), indicating that AR provides significantly greater interactivity than traditional PPT, reaching a statistically significant difference. The second highest t-value was observed for C5 (“Which medium requires more professional production skills?”), also with a t-value of 12.243 (p < 0.001). This result suggests that AR demands a higher level of technical skill to produce content effectively, especially in creating highly interactive HME analyses. Another item, reached significance at the 0.001, was C2 (“Which is better for presenting 2.5D images?”), with a t-value of 5.791 (p < 0.001). In AR, 2D images can be easily processed by removing background to simulate a 3D effect. This 2.5D presentation method is one of the simplest to produce in AR, by doing so, it creates a strong sense of 3-dimension and is visually impactful.

Moreover, there are also 3 items, C3, C1, and C6, reaching $p < .05$ significance. The item with the highest t-value of $p < 0.05$ was C3 (“Which is better for presenting video: PPT or AR?”), with a t-value of -3.574. This indicates that students preferred using PPT for video presentation during HME analysis. In PPT media, videos are projected on a large and stable screen, and remained unaffected by viewing angles, offering better visual quality. In contrast, videos in AR are viewed through the small screens of smartphones or tablets, which are easily to distortion or shaking, depending on the device’s position. Thus, the viewing experience of videos in PPT media is better than which in AR with statistically significant difference. One more significant item was C1 (“Which medium provides better text presentation?”), with a t-value of -2.962 ($p < 0.05$). Similar to video, text in PPT is displayed on a large, fixed projection screen, making it easier to read. In AR, however, text is limited by the smaller size of mobile screens, leading to relatively poorer legibility and presentation quality. The final item reaching $p < 0.05$ significance was C6 (“If there were no technical barriers, I would prefer to use PPT/AR”), with a t-value of 2.066 ($p < 0.05$). This suggests if there were no technical obstacles, students expressed their preferences for using AR, they are generally accustomed to using traditional PPT for HME analysis. Although spending the considerable time and effort on investing how to use AR in HME analysis, students are still willing to adopt AR in the future, which reflects a positive potential of AR media in design education and process.

5. Conclusion and Suggestions

The comparative analysis revealed notable differences between students’ experiences using traditional PPT and AR media in conducting HME analysis. When using PPT, students have no stress, whereas in AR they did not generally feel significant discomfort; however, statistical comparisons indicated that in AR students generated significantly higher levels of perceived pressure ($p < .001$). Nevertheless, students were willing to invest more time in producing AR-based HME analyses, suggesting openness to adopting new presentation media. Although AR-based HME analyses required more time and less familiar than PPT, students’ moods were not negatively affected, and also perceived more challenging and creative rather than boring traditional PPT.

In terms of media content comparations, removing the background from 2D images to create the illusion of 3D models in AR was found to be the simplest form of AR content production, while still producing a strong sense of 3d-depth. Video and text presentations in PPT benefited from larger projection sizes and stable displays unaffected by viewing angles, thus offering higher visual quality. In contrast, videos viewed via AR on smartphones or tablets appeared smaller and were susceptible to distortion or shaking with device movement; thereby reducing viewing quality. However, AR media offered significantly greater interactivity than PPT ($p < .001$). Producing highly interactive AR-based HME presentations required specialized technical skills; thus, students expressed a clear willingness to use AR for such analyses in the future.

However, current AR development software is not specifically designed for conducting HME analyses in design education. In this study, the platform of AR media was the META’s Spark AR, which required

students to master advanced module configurations to achieve interactive effects. To address this limitation, the one of further studies of this research will focus on developing a dedicated AR interface tailored to HME analysis in the design process, enabling students to more easily create and present interactive HME analyses.

Declarations

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Ethical Approval and accordance "Not applicable"

Consent to participate: "Not applicable"

All students provided informed consent prior to participation. Participation was voluntary, and data were collected anonymously.

Data Availability Statement:

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Author Contribution

I am the single author, who prepared all materials and manuscript text by myself.

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Figures

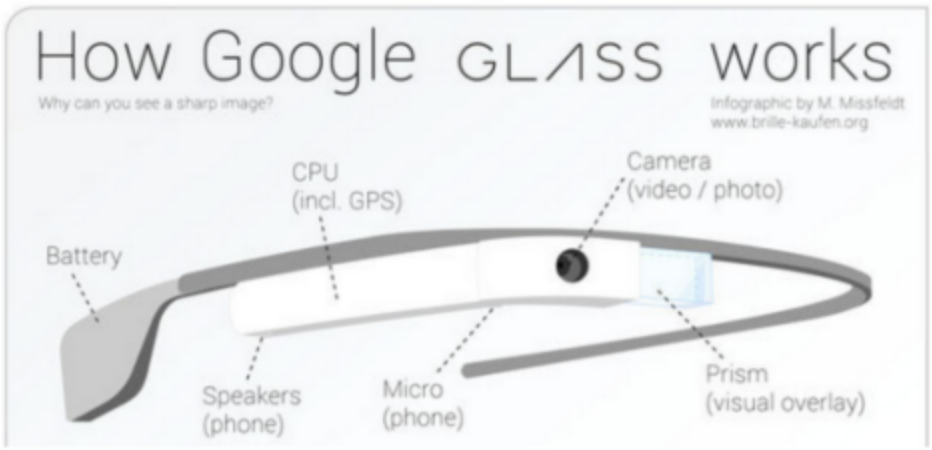


Figure 1

Google Glasses (Google, 2013)

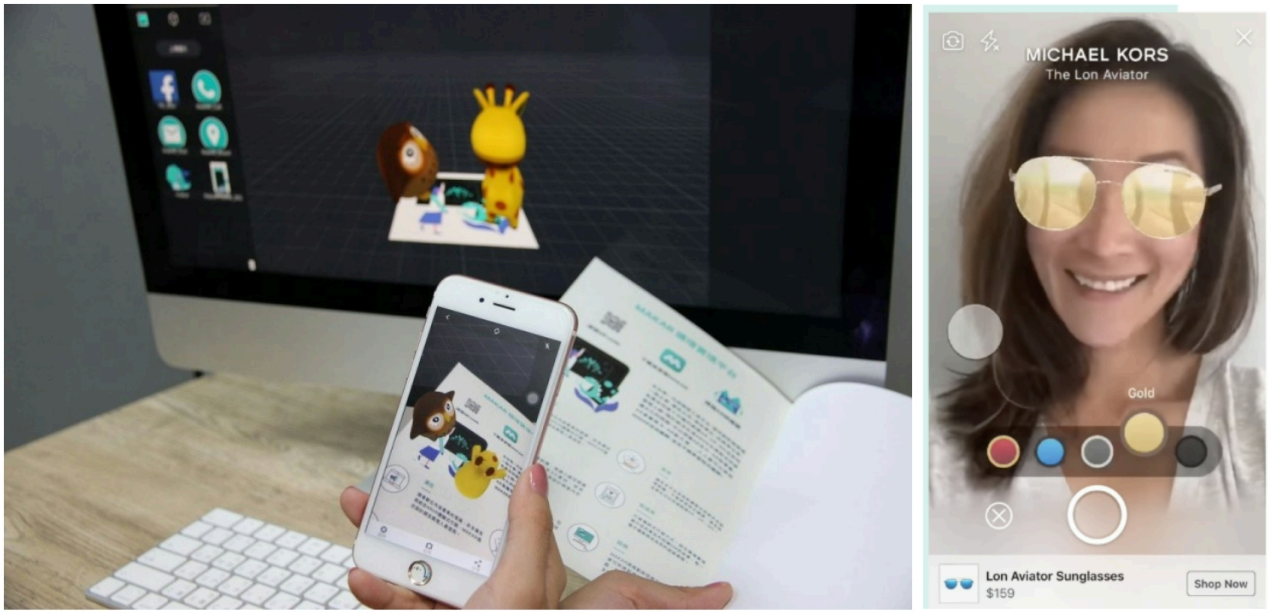


Figure 2

left: AR by MakAR; right: Spark AR Studio of Facebook



Figure 3

left: Text and narration in AR; middle: Transparent-background images; right: Videos in AR.