EFFECTIVENESS OF IMMERSIVE MEDIA TO ENHANCE 3D MODEL MAKING AMONG INDUSTRIAL DESIGN LEARNERS IN DESIGN EDUCATION

A Thesis submitted to the

UPES

For the award of

Doctor of Philosophy

In

Interaction Design

By

Shakti Banerjee

August 2025

Supervisor

Dr. Nilakshi Yein

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Dehradun- 248007: Uttarakhand, INDIA

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DECLARATION

I declare that the thesis entitled "Effectiveness of Immersive Media to enhance 3D model making among Industrial Design learners in Design education" has been prepared by me under the guidance of Dr. Nilakshi Yein, Assistant Professor of School of Design, UPES and Prof. (Dr). Anirban Chowdhury, Alliance University, Bangalore. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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DATE :21/08/2025

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CERTIFICATE

I certify that Shakti Banerjee has prepared his thesis entitled **"Effectiveness of Immersive Media to enhance 3D model making among Industrial Design learners in Design education"**, for the award of PhD degree of the UPES, under my guidance. He has carried out the work at the Department of School of Design, UPES.

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Recognized by the University Grants Commission (UGC), New Delhi

CERTIFICATE

(To Whom It May Concern)

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ABSTRACT

Design education is practical in nature, encompassing various learning modalities like workshops and model building while also cultivating soft skills. However, the pandemic altered this dynamic. With the shift to online classes, design institutes had to reimagine their teaching methods almost overnight. The COVID-19 pandemic gave rise to hybrid learning models, which, while necessary, brought their own set of challenges. One of the biggest hurdles has been figuring out how to effectively teach model-making skills in this new setup. In traditional online communication tools- like verbal, textual and even audio-visual methods- often fall short in meeting the interactive and tactile needs of design education. The shift made it clear that the online environment struggles to replicate the depth of engagement students experience in physical classrooms. This has sparked conversations about how to bridge the gap between digital and physical learning.

This thesis aims to understand how immersive media, such as augmented reality (AR) and virtual reality (VR), can influence and enhance model-making skills in industrial design students. The study aims to explore how these advanced technologies can be integrated into the learning process to benefit skill development. Researchers used a purposeful probability sampling method to select participants, ensuring a diverse group of students from various design disciplines. Exclusion criteria were kept for the participants who had no prior knowledge of 3D software for the Model Making/Prototyping course. The experiment was descriptive in nature and employed the one-group pre-test and post-test design of research, which enabled the researchers to see how the students' skills and experience with the technologies changed once they were used. The variables for the study included Perceived Engagement, Perceived Enjoyment, Perceived Acceptance and Cognitive Load. In the above tests, it is shown that design students thought that AR was easy to adopt, engaging and enjoyable as compared to 3D model making. This emphasises the potential that

AR has in enhancing the model-making process and making it more interactive for the learners. Psychometric questionnaires were employed to get quantitative data, and focus group interviews were also used. The NASA-TLX method was used to measure cognitive load. The findings indicated that students who study design subjects were more inclined towards the use of AR than the 3D model making.

This research introduces an AR-supported collaborative and AI-embedded system for model-making. It has the capacity to extract vertex and edge data, which can, as such, help transform a student's sketch from orthographic projection to 3D. It helps learners modify and visualise virtual models, and the orthographic sketch can easily be transformed into 3D shapes. However, this study also faced limitations. Time and resource constraints affected the scope and accuracy of the results. The study lacked extensive expertise in algorithm design and AI, and had a limited demographic representation due to a small sample size. These factors restricted the ability to generalise findings to all design students.

The thesis highlights the transformative potential of Augmented Reality (AR) and Virtual Reality (VR) in design education, emphasising their ability to enhance learning experiences, particularly in 3D. AR stood out as the most effective technology for fostering engagement, enjoyment, and acceptance among students, offering intuitive tools that reduce cognitive load and improve design iteration processes. This research study will be the thesis output that establishes a foundation upon which other researchers can build, using a coding tool to incorporate AI. By integrating these immersive tools, the study emphasises their potential to inspire growth and enrich teaching practices in design education.

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List of Abbreviations

2D:	2-Dimensional
3D:	3-Dimnesional
ACTA:	Applied Cognitive Task Analysis
AI:	Artificial Intelligence
AR:	Augmented Reality
ANOVA:	Analysis of Variance
CAMIL	Cognitive Affective Model of Immersive Learning
CAD:	Computer-Aided Design
DE:	Design Experiment
HBO:	Hybrid Blended Online
IoT:	Internet of Things
MD:	Mental Demand
MR:	Mixed Reality
MOOC:	Massive Open Online Courses
muCI :	Muscle computer Interface
NASA-TLX:	Nasa Task Load Index
PD:	Physical Demand
PD:	Physical Demand
PEOU:	Perceived Ease of Use
PLS:	Perceived Learner’s Satisfaction
PRQ:	preliminary research questions
PU:	Perceived Usefulness
VR:	Virtual Reality
RQ:	Research Question
XR:	Extended Reality

1 Chapter 1. Introduction

Chapter Summary*:* The use of Augmented Reality (AR), Virtual Reality (VR), and Extended Reality (XR) in design education, as these technologies enhance design pedagogy, will be discussed in this chapter. It demonstrates how learners can experience elements of spatial and interactive design through these immersive media. The authors also outline the advantages of these technologies, including increased creativity, collaboration, and practical activities, as well as the drawbacks, such as costs, challenges in integrating them into the curriculum, and ethical issues. However, as these technologies become more mainstream, they are likely to reshape the design teaching paradigm by altering how students visualise, prototype, and interact with design.

Keywords: Immersive Media, Design Education, Augmented Reality, Virtual Reality, Extended Reality

1.1 Research Context and Overview of Immersive Media

Immersive media, an amalgamation of Augmented Reality (AR), Virtual Reality (VR), and the lesser-known Extended Reality (XR) technologies, has transformed audience perceptions. Unlike traditional media, which depends on passive consumption, immersive media involves users in an interactive, multi-sensory environment. There are three principles that apply to how immersion is experienced worldwide: AR overlays digital content onto the real world, VR transports the user into a digital environment, and XR integrates both so seamlessly that the boundary between the real and virtual worlds becomes indistinct. This merging of realms offers notable opportunities for improvement, especially in design education, where the ability to visualise, manipulate, and experience designs within immersive environments revolutionises learning and creative processes.

The connection between the real world and 3D environments represents a significant advance in education technology. XR, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), is regarded as creating a range of immersive experiences. These range from completely computer-generated environments to simple enhancements of real life with computer graphics, providing environmental immersion for a near-real experience. AR stands out among these technologies because it allows users to freely engage in both the virtual environment and the physical world simultaneously.

XR technologies are transforming how education is delivered by creating dynamic and engaging learning experiences. Unlike traditional teaching methods, which involve passive information absorption, XR promotes active participation. For instance, in a history class, students can virtually immerse themselves in historical events, enhancing their understanding and retention. Similarly, in science education, XR can simulate complex chemical or biological processes, making abstract concepts more tangible and easier to understand (Cole et al., 2022).

Furthermore, XR is particularly valuable in medical, technical, and vocational education, where hands-on experience is essential. It allows students to practise complex tasks—such as operating machinery, performing virtual surgeries, or rehearsing emergency response scenarios in a safe and controlled environment—without the risks involved in real-life practice. This practical application of knowledge not only improves learning outcomes but also boosts students' confidence before they translate these skills into real-world situations. It is anticipated that Extended Reality (XR) will aid in distributing a wide variety of instructional materials, thereby transforming education and training (Stanney et al., 2023).

1.2 Definition of AR & VR and its application

Augmented Reality (AR) has proved to be a revolutionary technology in the very presentation of model manipulatives during the digitalisation age. AR enhances the real world by adding elements such as images, videos, and 3D models on top of it. This is usually done via mobile devices, tablets or AR glasses. It should be noted that, unlike VR, which displaces the user onto a completely synthetic space, which is purely virtual, AR enables layering of virtual images into the real space, thereby enhancing the interaction.

Figure 1.1. A student is trying out a VR headset and experiencing VR projects. (source: IMD Lab, MIT Institute of Design)

In healthcare, marketing, entertainment, and education, AR is widely used to enhance functionality. This AR improves how objects are viewed and connected in design (Arce et al., 2022). According to the study by Lee and Park (2020), AR allows product designers to visually prototype and test products, which is faster and cheaper than physical prototyping. AR assists students in understanding complex topics in meaningful and engaging ways. AR reduces the gap between the physical and digital worlds to improve user experiences.

Augmented Reality (AR) enhances the visualisation and engagement of physical components through dynamic displays. According to Silva et al. (2022), AR presents virtual images of tech-enabled products on screens, thereby improving customer experiences and product representation. In the business world, AR is vital for 3D product visualisation, allowing products to be depicted more effectively to customers. This AR supports decision-making, provides virtual assistance, and effectively connects the real and virtual worlds.

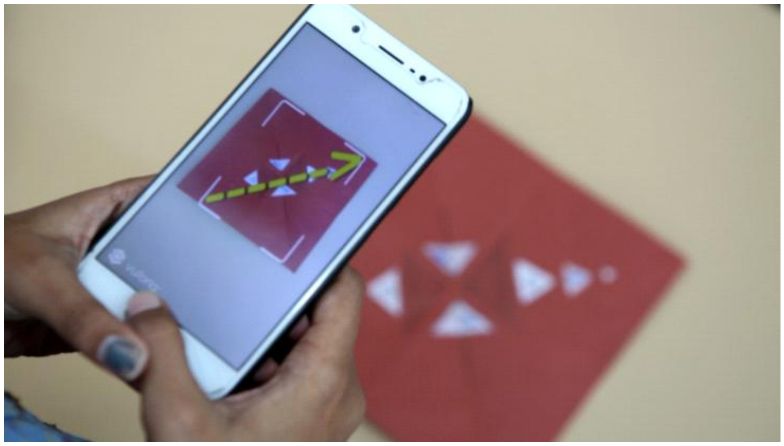


Figure 1.2. Learning Origami using the AR (courtesy IMD Lab, MIT Institute of Design)

1.2.1 AR for Industrial design learners

Augmented Reality (AR) enhances student engagement and replaces traditional learning with digital environments in industrial education (Carbonell et al., 2024). Today, digitalisation in education promotes AR use in industrial learning. Learning and retention can be boosted through AR, which features advanced interactive and engaging elements that go beyond the typical classroom experience. AR allows for the rendering of virtual elements that facilitate understanding of complex physical structures. Its ability to personalise the learning journey—by offering customised services, tracking student progress, and accommodating individual learning preferences—makes it more engaging and effective. This personalised approach boosts student engagement, creativity, critical thinking, and problem-solving skills, which are vital for success in industrial design (Kaplan et al., 2021). Moreover, AR supports collaboration by providing virtual collaborative environments, thereby reducing waste of materials and resources needed for creating physical models (Sadiku et al., 2022).

1.2.2 Virtual Reality (VR) & Augmented Reality (AR) concepts in 3D model making

3D model development processes in both "Virtual Reality (VR)" and "Augmented Reality (AR)" are based on the principles of visualisation. VR offers students interactive methods for creating models to simulate a world where they can interact with virtual objects, unlike AR (Banerjee, Srivastava, Chowdhury, 2021). According to Eastman and Computing, students can experiment with design iterations, explore spatial relationships, and understand proportions and scale through interactive experiences (Eastman & Computing, 2001). Hay et al. (2020) analysed past, present, and anticipated future trends in design cognition research, which involves the processes and representations of thinking within the context of design. With the support of a community focused on design cognition, the authors conducted a literature review covering various topics within this field and identified a lack of interest in certain research topics and methodologies. To shift the scientific perspective on design cognition studies, they proposed a roadmap emphasising the development of innovative methods, including unobtrusive and ecological measurement, the application of AI, and more advanced theoretical frameworks. AR enables students to see virtual models within real-world settings. It facilitates the development of design concepts and uses real-time feedback to incorporate virtual features into real objects. Based on these concepts, learners evaluate the appeal and engagement of their ideas.

During Industrial Design's model-making course, students need to understand principles like form, shape, and space. They must have expertise in using manual tools for creating 3D models. Understanding tactile attributes and facing challenges in digital visualisation using 3D software are important. In model-making courses in Industrial Design, students gain a foundational understanding of form, shape, and space. Skilful use of manual tools is essential for creating accurate 3D models and exploring the tactile qualities of various materials. Additionally, students learn to interpret and translate these physical attributes into digital formats, addressing the challenges associated with 3D modelling software. This integrated approach develops both hands-on and digital visualization skills, which are vital for professional practice (Ismail & Hassan, 2023).

The course starts with sketching concepts, creating CAD models, and physical materialisation. Faculty guides students in correcting forms and refining designs. Traditional teaching methods for 3D visualisation in design education face several challenges. Limited classroom space restricts hands-on activities and model-building. Managing larger student groups reduces individual faculty interaction, hindering personalised guidance. Understanding 3D dimensions, proportions, and perspective views can be difficult when relying solely on static images or two-dimensional sketches. These limitations often create gaps in spatial understanding and slow student progress, which ultimately affects the learning experience (Kaźmierczak et al., 2024). User interfaces and experience design greatly influence student engagement. Learner motivation rises with intuitive AR interfaces and clear instructions. The quality and realism of AR visualisations are vital for learner immersion. AR customisation and interactivity are important for student engagement. Interactive lessons, gamification, and guidance enhance involvement. A supportive learning environment encourages learners to develop AR-based modelling skills.

An environment with clear instructional materials, opportunities for peer collaboration, and expert support promotes learners to explore, experiment, and master AR-based modelling skills (Wohlin & Aurum, 2015). Access to AR-enabled devices and institutional adoption of AR significantly impact learning; therefore, incorporating AR into the curriculum is essential. A brief review of this chapter highlights several key findings. Notably, there is a gap in applying emerging technologies to aid design education, indicating potential for further research. Additionally, studies are limited on how AR and VR can support the development of motor skills in design courses. Moreover, there is a recognised need for using AR to visualise spatial dimensions within educational contexts.exts.

1.2.3 Role of Immersive Media in Design Education

Traditionally, design education has relied on visualisation techniques such as sketches, models, and digital renderings (Figure 1.3). However, immersive media transformed this approach, enabling students to interact and experience designs in a more spatial manner. For instance, virtual reality (VR) lets students explore architectural spaces or product concepts as if they were physically present, providing insights into usability, scale, and proportion that are often difficult to

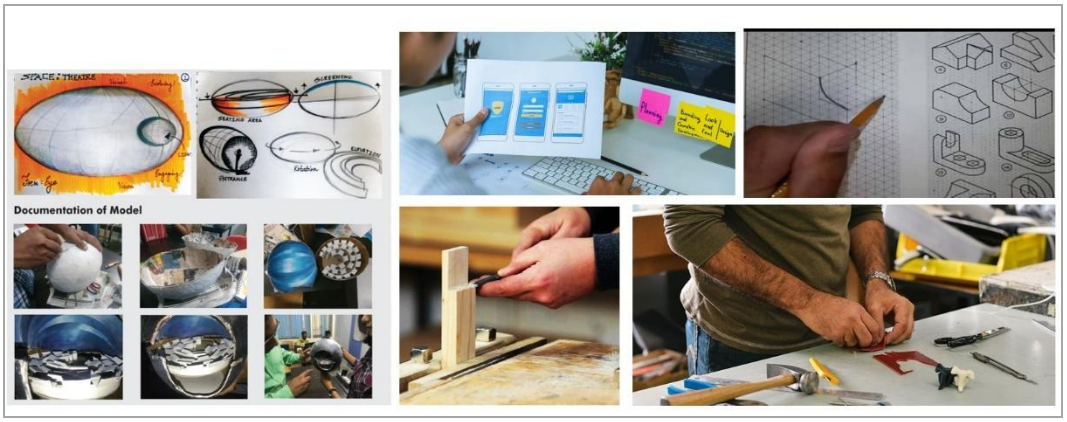


Figure 1.3 Different skill sets in Design education (source: students' work from MITID)

achieve with conventional methods. Augmented reality (AR) takes a step further by augmenting digital models onto real-world environments, enabling students to analyse context and make adjustments in real time. XR further extends these capabilities by integrating physical and virtual elements into a cohesive experience, fostering innovative approaches to problem-solving and creative thinking (EdTech Empire, 2023).

1.3 Design Education in India

Design education in India has evolved significantly over time. Our economy now increasingly embraces practical design. As the design industry grows, educational opportunities in this field have expanded. India's design sector is poised for strong performance due to the country's demographics, rising awareness of the value of education, and people's willingness to explore new ideas. Historically, design education in India was initiated in 1961 with the establishment of the National Institute of Design (NID), inspired by the Ray and Charles Eames India Design report (Balaram, 2005). The shift in mindset and actions can be traced back to Rabindranath Tagore. Shantiniketan's efforts to revitalise rural areas remain a prominent story in design history (Balaram, 2005). As policies and markets have naturally evolved, design education has become increasingly appealing to those pursuing careers in the field. For effective design education, students need to engage with real-world projects and create meaningful connections with their environment.

1.4 Design Education and the Pandemic

The COVID-19 pandemic underscored the importance of online technologies in education, prompting institutions worldwide to close and disrupting academic schedules. Many universities adapted by establishing online learning environments to continue their academic programmes (Mittal et al., 2022). Students faced various uncertainties and challenges while studying different subjects and developing skills.

Design education, with its focus on practical skills and hands-on experience, faced unique challenges during this shift. While lecture-based content could be delivered virtually, studio-based courses were difficult to adapt (Miller & Beebe-Centre, 1956). Miller's 1956 work marked a turning point in cognitive psychology by identifying the limited capacity of human memory, sparking the behaviourism shift and initiating the cognitive revolution. Other significant work, such as that of Abu-Rayyash and Alhawamdeh (2024), examined the cognitive workload involved in translating post-editing within increasingly complex neural machine translation and post-editing workflows (Abu-Rayyash & Alhawamdeh, 2024). Their approach to keystroke data logging contributed to both human-computer interaction and the automation of translation processes, aligning with Miller's ideas and current trends in translation research. In India, design institutions facilitated online classes, but a hands-on learning approach—reliant on workshops, tools, and typically involving one-on-one interaction between faculty and students—was also relevant. Nevertheless, during the pandemic, both faculty and students recognised that hands-on courses could be successfully conducted online.

In the Industrial Design curriculum, in a model-making course, students must comprehend concepts such as form, shape, and space in order to construct a model. Furthermore, design students must use a range of hand tools in order to create three-dimensional models. To build a physical model, pupils must grasp dimensions, materials, and tactile properties (i.e., texture). Nonetheless, individuals may have difficulties understanding the three-dimensional visualisation that

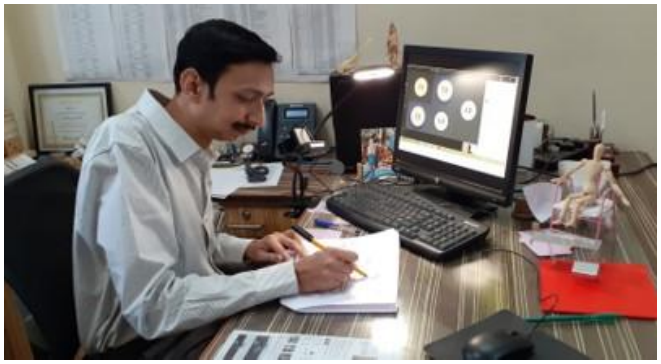


Figure 1.4 Design Faculty conducting an online course, demonstrating on a drawing sheet in front of a camera during the COVID-19 pandemic. (Image source: Author, 2020)

happens when their thoughts are digitally represented using 3D software. During COVID-19, design faculties adopted an online medium to conduct design modules using demonstrations on camera or using software tools. Refer to Figure 1.4 and Figure 1.5. Learning practical skills online presents inherent difficulties. This prompted researchers in educational technology to seek effective methods to communicate in distance learning. Here, Virtual reality (VR) and other immersive media appear as promising platforms for these kinds of tasks. Through the immersive learning environment that virtual reality offers, students' comprehension of particular course objectives could be improved. VR, for instance, can enable

Figure 1.5 Design Faculty conducting online course using Wacom during the Pandemic. (Image source: Author, 2020)

interactive learning experiences that simulate the model-creation process in design classes (Ertmer & Newby, 1993). As online learning gained broader acceptance following COVID-19, Immersive technologies like Virtual Reality (VR) and Augmented Reality (AR), have become more popular, and their applications are better comprehended. Many educational institutions have now recognised the benefits of a hybrid instructional approach. Online platforms will remain a teaching and mentoring tool even beyond the pandemic. Beyond the pandemic, hybrid, blended, and online (HBO) learning models allow students greater flexibility to learn independently, expanding beyond the confines of physical classrooms (Kolb et al., 2014). The HBO Model integrates classrooms and fully remote education into a single cohesive framework known as the Hybrid Blended Online (HBO) Model. It allows the delivery of instruction at the learners' preferred pace and is beneficial for enhancing participation and engagement. The HBO model is beneficial for students with specialised needs, as well as those enrolled in STEM courses. It enhances teamwork, personalised advancement, and active involvement by providing the learners with diverse resources and ways of interacting. (Ahuja et al.,2023)

1.5 Immersive Media's Advantage in Design Education

Introduction of immersive media in design education offers several advantages. First, it facilitates experiential learning, enabling students to engage with design concepts in a hands-on manner. This is beneficial in the fields of architecture, interior design, and industrial design, where spatial awareness and user interaction are critical. By immersing students in a simulated environment, they can experiment with different design solutions, observe their impact, and iterate rapidly, gaining a deeper understanding of design principles. Immersive media fosters collaborative learning. It enables students from various locations to work together in real-time on design projects within virtual environments, sharing ideas and feedback as they would in person. This capability is particularly valuable in our increasingly global society, where interdisciplinary collaboration is essential. Tools like Gravity Sketch and Mozilla Hubs facilitate these interactions, creating a dynamic and inclusive learning environment (Georgieva et al., 2024).

Furthermore, immersive media offers a way to broaden access to design education for every prospective learner. Proper infrastructure can now provide access for students situated in remote locations to advanced design education, which was previously unreachable. It is possible for students from less privileged backgrounds to attain high-level design education and training, which was previously unavailable to them. Through VR and AR, any student can access from anywhere in the world. Also, it can be made available to them at any time. It can help students grasp essential skills and provide them with the real-world experiences that the industry demands. (EdTech Empire, 2023).

1.6 Challenges and Considerations

While immersive media offers great potential, there are challenges to integrating it into design education. The cost of implementation is high for procuring high-quality VR headsets, AR devices, and the necessary processing power can be expensive for many institutions. Additionally, creating and maintaining immersive content requires specialised expertise and a significant investment in software development and content creation. To make immersive media a viable option, institutions must carefully assess their budgets and explore funding opportunities such as grants and partnerships (EdTech Empire, 2023).

Another hurdle is the need to revise curricula. Traditional design programs may not be equipped to fully integrate immersive media, requiring a reevaluation of course structures, learning objectives, and assessment methods. Educators have to use immersive tools and also design experiences that leverage the unique capabilities of AR and VR. This shift calls for more interactive, student-centred approaches, moving away from the conventional lecture-based model (Georgieva et al., 2024). Usage of immersive technology also raises privacy and ethical concerns. As students interact with virtual environments, large amounts of data are generated, raising issues around data breaches. Institutions must ensure policies are in place to protect student information and that immersive experiences are safe and inclusive for all users.

1.7 Future Directions

The future of immersive media in design education looks promising. As technology advances and becomes more accessible, we can anticipate more sophisticated and seamless uses of AR and VR in design Institutes. For example, the development of haptic feedback devices will allow students to "feel" materials and textures in virtual environments, enhancing the tactile experience of their designs. Moreover, AI-powered tools will enhance personalisation by adapting learning experiences as per student's needs and preferences.

The distant future of immersive media in education will also be shaped by ongoing research into its impact on learning. Studies are exploring how these technologies can further engagement, foster creativity, and improve learning outcomes. As more evidence emerges and best practices are established through case studies from early adopters, we can expect immersive media to become more widely adopted in design education (Interaction Design Foundation, 2024). The amalgamation of 3D environments brings an exciting new dimension to pedagogy. Today, technologies such as Virtual, Augmented, and Mixed Reality (VR, AR, MR) span an entire range from real-life locations enhanced with virtual stickers to 3D environments and content entirely generated by computers. The depicted immersive technologies provide 360-degree visuals, real-life audio, and haptic feedback during the learning process, therefore enriching the experience.

Furthermore, as fully automated classrooms, AR, MR, and VR-powered learning also help enhance motivation and association through real-life interactive systems that respond to voice, gesture, and movement, engaging students in a new and more immersive way (Nazlidou et al., 2020). This study focuses on identifying the differences between Virtual Reality (VR) and conventional 3D software in showcasing 3D models, aiming to understand the advantages and disadvantages of both technologies. As an initial step in the research process, the scholars try to analyse the impact of VR on the effectiveness and usability of 3D modelling as compared to the impacts of conventional 3D software approaches. The first phase of the research aims to identify the effectiveness, usability, and overall impact of VR as a tool for 3D modelling, compared to the conventional techniques offered by standard 3D software. In the following section, the study shifts focus to comparing

Effectiveness of immersive media to enhance 3D model making among industrial design learners in design education

Chapter 1 – Introduction

Overview - Research motivation
Pandemic and Design education scenario.
Immersive media such as AR/VR in design education.

Chapter 2 – Literature Review, Research Gap, Research questions, Aim and Objectives
Context studied in Learning Theories, Cognitive Psychology Parameters, Design Education, Immersive Technology/ AI tool

Chapter 3 –
Research Methodology
- Sample Size and Sampling Technique,
- Tools & Methods of Data collection
- Study setting & Study Design

Establishment of Generic Hypothesis

Chapter 4 –
Conceptualisation in AR and VR for model making and its validation
- Objective
- Conceptualisation on AR and VR based instructions for Model making.
- Heuristic study
- Results & Discussion
- Questionnaire
- Study Conclusion

Chapter 5 –
Usage and impact of VR Application in 3D model making
Impact of VR technology on
- the 3D concept visualisation
- Analysis of cognitive load
- Comparison of VR application with 3D conventional software application
- Methods
- Results & discussion
- Study Conclusion

Chapter 6-
Application of AR in comparison to usage of conventional 3D software versus VR application
- Experiment Design
- AR application and 3D conventional software application
- AR Vs VR comparison
- Results & Discussion

Chapter 7 - Conclusion-

Limitation and future Scope

Figure 1.6 Thesis Flow Chart

Augmented Reality (AR) with traditional 3D software, examining AR's potential as a 3D visualisation tool. The goal is to determine whether AR offers a more engaging, practical, or efficient alternative to conventional digital modelling techniques.

Lastly, the study conducts a validation process that directly compares AR and VR to evaluate their strengths and weaknesses in 3D visualisation and model creation. Through this comparison, this research aims to provide key insights into which technologies are best suited for enhancing the 3D modelling experience. Comprehensive qualitative and quantitative research methodologies are implemented throughout the analysis. Quantitative methods generate quantifiable data regarding performance, efficiency, and accuracy across various platforms, while qualitative methodologies offer insights into user experiences, perceived benefits, and obstacles. When combined, these methodologies establish a solid foundation for the study's conclusions. The thesis workflow and chapter details are briefly presented in Figure 1.6.

1.8 Chapterisation

Chapter 1: **Introduction**

Design education has a hands-on approach - Apart from soft skills, many courses include workshops and model development.

1. During the pandemic, all of the Design institutes began conducting online classes.
2. Post-pandemic: design institutes adopted Hybrid Blended Online (HBO)learning approach.
3. One of the crucial factors influencing a learner's ability to succeed in an online learning environment is Cognitive Load.
4. Cognitive Load refer to managing the volume of information and task complexity, which can impact understanding and retention.
5. Immersive media as an innovative intervention showed as a promising teaching aid tool.
6. One needs to have a prior understanding of the tool/ technology to get the complete experience or help to comprehend better.

7. The validity of the use of augmented reality/virtual reality (AR/VR) for more effective teaching in design education is a question that needs to be answered

Chapter 2: **Literature Review, Research Gap, Research Questions, Aim and Objectives**

1. Listed below are domains within which the relevant Research papers were classified in the Literature Review.
    - Learning Theories
    - Cognitive Psychology/Education Pedagogy
    - Design Education
    - Immersive Technology / AI tool
2. After the study of the Literature Review, it is clear that there is a dearth of published literature available for publication in the area of the application of VR and AR for the practice of Design education.
3. There have been use cases of deployment of Immersive media in medical teaching, mechanical engineering education, architecture education, K12 education of Schools and even in vocational training programs; however, studies on the implementation of VR/AR were not much found for design education.
4. Over the past few years, it has been noted that there is a rapid increase in the number of Design Institutes in India. The design education scenario also changed in India. Nevertheless, not much is being practised with new technology, which is relevant for design pedagogy.
5. Lack of literature focusing on the use of Immersive Media, such as VR and AR, in the design courses aimed at motor skill development.
6. The aim of this research is to look into how 3D model making in design education is enhanced by using VR and AR technologies.
7. Establish the comparison between the VR/ AR approach against more traditional 3D software-based applications.

8. Recognising factors affecting learner engagement with VR/AR applications, assessing the impact of cognitive workload and usability, and acceptance of such immersive media.

Chapter 3: **Research Methodology**

1. Hypothetico-deductive research method applied in the thesis with appropriate inductive and deductive research structures.
2. The respondents were involved in Qualitative and Empirical Research through a Psychometric Questionnaire.
3. The complete thesis has been spread in three major research studies:
   - First is of brainstorming VR instruction-based and AR instruction-based concepts developed, and heuristic experts' analysis done.
   - Second, a comparative study of the use of traditional 3D software for model making versus the use of VR-based tools.
   - Third, a comparative study of the use of 3D software for model making versus the use of AR-based tools.
   - In the end, a comparison study of the AR tool versus the VR tool for model making.

Chapter 4: **Developing concepts in AR and VR for 3D model making and validation.**

1. A pilot concept has been developed for using VR-based instruction and AR-based for 3D model making.
2. The VR-based concept for 3D model visualisation allows students to overlay hand-drawn sketches with their 3D models to assess accuracy.
3. Additionally, AR-based concepts were brainstormed to align models with real environments, providing visual cues.
4. Heuristic analysis was done by recruiting five design experts (through purposive sampling) who have skill in 3D visualisation, who evaluated parameters like concept uniqueness, functionality, interface aesthetics, and visual feedback.

5. The mean score given by the heuristics experts was higher for the AR-based instructional interface than the VR-based instructional interface, indicating that AR is more appropriate for model making.
6. However, it is not clear whether the AR concept will be accepted by the student group. Hence, there is a need for the evaluation of the proposed AR prototype concept with 3D model learners.
7. Also, conducting Experimental testing for both VR and AR applications with actual learners would give more insights.

Chapter 5: **Use of VR in 3D model making and its effectiveness.**

An experiment design has been conducted with a cohort of 64 students of various design disciplines aged 19-26.

1. Initially, purposive sampling was used for selecting participants from various design disciplines from the same Design institute,
2. The inclusion criteria were that all the participants were from design disciplines.
3. Exclusion criteria were kept in sampling so that the students who do not have any prior knowledge of 3D software for the Model Making/Prototyping course.
4. A subsequent phase used non-probability random sampling.
5. An initial Questionnaire test was done to assess students' understanding of 3D concepts.
6. First, a task of creating a 3D bottle given to participants using any conventional 3D software which they are aware of, such as Fusion, Blender, etc.
7. Then, a VR workshop was conducted, introducing Gravity Sketch for basic 3D form creation. Exposure to the VR tool – Meta Quest 2.
8. One-group pretest-posttest design methodology followed. Within-subjects Study; cross-sectional, within-group, between-subject study done.
9. Students repeated the bottle task using VR tools.

10. Their experiences were observed and documented.
11. Cognitive load was measured in both scenarios using NASA-TLX, calculating means and standard deviations.
12. A post-task comparative study (conventional vs. VR) used a Likert 1-5 scale using psychographic questionnaires.
13. The study encompassed a total of 128 students. The sample size was carefully determined based on exclusion criteria, primarily the absence of prior 3D knowledge. Only students with a foundational understanding of conventional 3D software were included in the study.
14. Dependent variables included perceived engagement, perceived enjoyment, and perceived acceptance. Also, the time factor consumed in 3D conventional software and when using the tool-based VR/AR is observed as well.
15. The mean value of usability for traditional 3D-based demonstrating programming was a little higher than that of VR-based. The outcome showed that the apparent convenience for utilising 3D regular displaying programming is altogether more than VR-based 3D in terms of precision
16. The mean acceptance rating for VR-based 3D is significantly higher than for conventional 3D software. This indicates that users are more receptive to VR-based systems, suggesting greater potential for adoption compared to traditional 3D software.
17. Perceived use of use, Precision, Perceived Enjoyment and Perceived Acceptance were the parameters used for analysis.
18. The long **continuous usage of VR** takes a heavy toll on the eyes, and dizziness in the head is one of the concerns that technology-improved advanced Headgear may address in the future.
19. Use of Virtual Reality to create models, it is easier to collaborate and make changes to the models, as well as easily visualise them in 3D space.

20. The gestural, intuitive way of creating 3D models using VR helped the design thinking ability in 3D modelling visualisation

Chapter 6: **Application of AR for 3D modelling and comparative analysis.**

1. Experimental Design same as Chapter 5
2. Rotation Method – A varimax rotation with Kaiser Normalisation was used in the questionnaire. Applied the Rotation method in order to deduce redundant values with dimension reduction. Considered values more than 0.7 are taken further for analysis.
3. A Chi-square value of 21.35 indicates a statistically significant relationship between the perceived ease of use and the variables being analysed
4. NASA-TLX registered a high Cronbach's alpha, which means that the index is a reliable one when used for Perceived workload in the analysed context.
5. Industrial design learners using the AR App for 3D model-making exhibited Perceived Engagement Mean more than the traditional 3D software.
6. The AR experiment extracted vertex and edge data from 3D visualisations to identify single-plane sets in the spatial system.
7. The AR system first scanned the form's sketches, including plan and side views, created by design students. Integration was simplified using AR Foundation in Unity (Game Engine software).
8. Extracted vertex and edge data, mapped orthographic views, and identified vertices belonging to single planes in 3D space.
9. Advanced AI tools were proposed for vertex detection, edge detection, and distance mapping, enabling the extraction of 3D spatial information for integration with AR.
10. This research introduces an AR-supported collaborative and AI-embedded system for model-making. It has the capacity to extract vertex and edge data, which can, as such, help transform a student's sketch from orthographic projection to 3D. It helps learners modify and visualise virtual models, and the orthographic sketch can easily be transformed into 3D shapes.

11. The findings indicated that the use of both AR and AI technologies enhances industrial design education, particularly in 3D model development, improving learning outcomes for design students.
12. The data shows that AR provides higher perceived enjoyment compared to traditional 3D software. Additionally, AR has a lower standard deviation than traditional 3D software, indicating more consistent enjoyment levels among users. This suggests that AR not only enhances enjoyment but also offers a more uniform experience.
13. For Perceived Acceptance Mean analysis, the traditional 3D software mean was significantly lower than the AR.

Chapter 7: **Conclusion**

1. Industrial design learners in 3D with an AR app give significantly higher ratings of perceived engagement, ease of use and enjoyment and lower cognitive workload than the VR app.
2. In comparison to the use of VR, industrial design learners using AR technology for 3D model-making will exhibit higher levels of learning engagement.
3. The mean of the cognitive load of the VR App was high, and the NASA Task Load Index (TLX) scores were lower in the AR-based system. Hence, the AR-based system has more potential than the VR App.
4. AR has shown more Perceived engagement as compared to VR.
5. The AR teaching methods can stimulate learning, generate learning efficiency, increase enthusiasm, break time and space limitations and even reduce teaching costs.

Outcome of this thesis

6. Using AR in 3D visualisation provides more time and freedom for exploration, allowing students to experiment with different forms before finalising one for model making.
7. Enhanced visualisation of complex designs and structures.
8. Interactive models allow for real-time changes and feedback.

9. The immersive media tool AR helped students to visualise a 3D model and finalise the shapes and forms before translating them with material. This approach reduces the need for physical materials, potentially lowering costs.
10. Facilitates remote collaboration and sharing of models with peers and instructors.
11. Increases student engagement and motivation through immersive experiences.
12. Technical glitches or software bugs can hinder the experience.
13. Relies on an extensive choice of platforms with a reliable internet speed and connectivity for performing tasks optimally.
14. The interactions between faculty and students during online sessions would be influenced by internet speed.
15. Over-reliance on AR might reduce hands-on skills and physical model-making proficiency, and overlook physical model imperfections that only tactile feedback can reveal.
16. Thesis output establishes a foundation or a basis upon which other researchers can build.
17. The Thesis output gives a basis for another researcher to work further on.
18. The thesis can explore the benefits for design faculty, who can adopt AR as a mode of instruction. Faculty can use AR to provide feedback on students' 3D visualisations remotely, also at their convenience.
19. Faculty need to learn how to use AR.
20. The thesis can foster collaboration between educational institutions, technology developers, and researchers, driving the evolution of AR in education.
21. It is a resource that will be effective for the E-learning industry, where trends are geared towards providing individualised learning experiences that satisfy the learner.

1.9 Key takeaway

Immersive media, with its ability to create engaging, interactive, and spatially aware environments, is poised to transform design education. By offering new ways to visualise, experience, and collaborate on design projects, AR and VR are not only enhancing the learning outcomes but also expanding the possibilities of what design education can achieve. However, the successful integration of these technologies requires careful planning, investment, and a commitment to address the associated challenges. As the field continues to evolve, Immersive media will surely become increasingly important in determining how design education develops in the future. In this thesis work, the scholar has focused more on the comparison of AR and VR in Design Education with special emphasis on the 3D Model Making course.

2 Chapter 2. Literature Review

Chapter Summary: This chapter explores the use of immersive media technologies like AR, VR, and XR in education, focusing on their ability to change teaching and learning through the use of hands-on, interactive, 3D spaces that improve learning retention and experience-based learning. It explores the evolution and implementation of these technologies across educational contexts, analysing their impact on learners and instructors. Drawing on case studies and current research, the chapter discusses the benefits, such as increased engagement, motivation, and personalised learning, alongside challenges like technical and logistical hurdles. It also explores the implications of these advancements for educational equity and inclusivity, providing insights into how immersive media can transform traditional education and create engaging learning experiences. The aim of this review is to offer valuable guidance for educational scholars, like ourselves, in developing immersive technologies involvement that unveils the academic ability of Immersive Media. Instead of evaluating the quality of VR and AR applications or the rigour of educational research, this systematic literature review offers a clear pathway for researchers to explore the potential of immersive media.

Keywords: Education, Educational Technology, Experiential Learning, Immersive, Virtual Reality, Personalised Learning.

2.1 Background of Immersive Media

Over time, many educators have investigated various methods and resources to enhance learning experiences. Immersive. The more recent forms of technology, such as virtual realities (VR) and augmented realities (AR), which are examples of immersive media, have gathered the interest of educators and researchers in recent times (Sherman & Craig, 2018). Unlike earlier virtual reality platforms such as Second Life or traditional online games displayed in 2D, immersive technology, such as immersive cinema, gaming, and storytelling, uses 2D and 3D projections in conjunction with sophisticated motion sensors and requires powerful graphics processors. A continuous series of stereoscopic images is generated on a head-mounted display while the procedure progresses.

Just as in reality, the users interact with the tangible surroundings respectively, in a similar manner, when technology integrates with Immersive Media Design, it creates a vivid comprehensive dimension which enables users to converse with 3d items in the virtual environment (Bailenson, 2018; Feng et al., 2018). Immersive media is regarded as a powerful 3D visualisation tool that offers the ability to present a different perspective, transforming it into an experience within a virtual world (Slater, 2017). The number of studies dedicated to the educational potential of Immersive technology is exploding due to the enhancement in areas of accessibility and accuracy (Radianti et al., 2020).

Utilising Immersive Media Design (IMD) allows for intricate instructional setups that can facilitate the attainment of targeted learning objectives. The field of education and training shows promise in developing the procedural knowledge necessary to tackle intricate challenges in new or unfamiliar work environments (Hamilton et al., 2021).

As expressed in the Cognitive Affective Model of Immersive Learning (CAMIL), a user's sense of presence, as well as control, are the critical factors for effective learning within the context of immersive media. Elements that are control features, as well as immersion level and representational authenticity, can increase these aspects (Makransky & Petersen, 2021). Learning in the context of media, the significance of not overstating the immersion is absolutely the learner's sense of control and independence within the intentional engagement in offered activities.

2.2 Essential information for understanding Immersive Experience

Researchers emphasise the need to acknowledge the limits of technology-supported learning environments, such as what elements of interactive learning capture attention, and how these environments merge with pedagogy and teaching methods (Klopfer, 2008; Mikropoulos & Natsis, 2011). The perceived benefits of VR/AR applications to the educational process are increased immersion, better understanding of 3D structure, learning by doing, more collaborative activities and the ability to practice in real-life situations without risks. Augmented Reality (AR) is a profoundly transformative technology having a growing impact on both the academic world and the world of entertainment. AR applications in education improve the motivation, creativity, self-efficacy, and spatial skills of the students. In the field of entertainment, AR is offering modern ways of interacting with content, and much traditional information is being presented in a modern and engaging manner (Kokkinidis & Folina, 2024). The role of augmented reality in higher education has been acknowledged for its ability to boost learner engagement, promote active learning, and facilitate understanding in different areas of study. With augmented reality, it is possible to combine practical and theoretical work, as digital information can be projected onto the real world.

In their systematic review, Sakr and Abdullah (2024) documented that AR research is highly concentrated in the domain of higher education. How can the advantages of VR and AR be utilised to improve learning in virtual environments? An analysis of how educational researchers utilise the unique characteristics of Virtual Reality or Augmented Reality to create learning activities would provide important perspectives into the educational possibilities of immersive technology (Sakr & Abdullah, 2024). The framework of Augmented Reality and game-based learning are two strategic pathways which are explored by Wu, Lee, Chang and Liang (2013) and by Abdul Jabbar and Felicia (2015), respectively. However, the literature assessment, which consists of comprehensive and systematic documentation in various design experiential learnt activities and patterns that sync in with VR and AR's essential features or those which are identified in prevalent design approaches, is recognised to be absent. Radianti et al. (2020) performed a review in which they underscored several design elements, emphasising a pervasive problem of insufficient detail concerning the degree of integration and the relationships to learning. Process for Literature Review and Formulation of Conceptual Framework.

Rather than assessing the quality of VR and AR applications, this systematic literature review provides a focused pathway to explore Immersive Media's transformative capabilities in education. It does so by examining how VR and AR-based learning activities have been designed and are implemented for achieving a set agenda, and how they lead towards creating distinct learning experiences within the journey. The review ultimately seeks to propose a practical tactic for researchers to investigate the educational prospects that Immersive media offers. The mental schema building technique was utilised to build the conceptual framework on instructional Immersive Media systems, based on information available in related literature.

This review highlighted the essential design elements that would enhance educational experiences in Immersive learning environments, as discussed in the current literature. Educational Augmented and Virtual Reality (AR/VR) learning environments offer exciting possibilities, but it's important not to overlook the technological and educational challenges involved. A review by Radianti and others in 2020 found several design elements, but pointed out that there is still confusion about how to effectively integrate these technologies and relate them to learning outcomes. This assessment coincides with Dede's (2017) immersion using the interface design concept, which incorporates sensory, doable, storytelling, and social patterns. The framework of Dede’s design of immersive interface combines different ways people interact and engage with words, which can be enhanced as well.

2.3 Sensory

In a virtual environment, to simulate a sense of physical presence, a range of sensory-motor stimuli (Dede, 2009; Dede et al., 2017) can be a key and essential feature to foster user engagement. Research by Castro and Tumibay (2021) in online learning highlighted that advanced course design, strong instructor presence, interactive participation, and effective technology integration were crucial for student satisfaction and perceived achievement in asynchronous and hybrid settings. Meta-analyses showed that higher student engagement boosted motivation and performance while reducing feelings of isolation (Castro & Tumibay, 2021). Among various strategies, learner-to-instructor engagement was particularly valued for its positive effect on satisfaction and learning outcomes in online courses. Meanwhile, in the real world, people know it is safe for them to walk forward. This demonstrates how a user's perception is influenced by the involvement of authentic 3D graphics and human sensory-motor signals, which act as a grounding point for a shift in the perception of reality and spatial awareness (Slater, 2017).

As posted in Dalgarno and Lee (2010), and also in Sanchez Vives and Slater (2005), a specific sensory stimulus has been shown to augment the awareness of bodily presence. The studies conducted later in the decade clearly demonstrate the importance of 3D visuals in enhancing the experience, along with the use of spatial audio and haptic feedback. The level of physical immersion experienced by users is influenced by the choice of VR and AR hardware, such as stereoscopic displays and wide fields of view, as well as software architecture (Cummings & Bailenson, 2015). Wang et al. (2024) conducted a comprehensive analysis of collaborative social engagement among multiple users through extended reality (XR) technologies and observed improvements in user presence, immersion, and agency within collaborative spaces. From this, they drew conclusions on the social interaction and engagement capabilities of multi-user XR systems across various domains. The metaverse is a blended universe that connects social spaces, merging the physical realm with a digital environment. It offers continuous social networking and multi-user interaction through immersive experiences.

Gargrish (2023) provided analysis and developed classifications, pedagogical alignments, and design principles, and acknowledged the advantages and limitations of AR integration in education. The study indicated that AR represents a conceptual approach, which combines real-world elements and digital information in various ways to facilitate learning. The document included classifications, pedagogical alignments, and design criteria, and highlighted both the benefits and challenges of using AR in education. Their analysis encompassed classifications, pedagogical alignments, and design principles, and underscored both opportunities and difficulties in incorporating AR into educational environments.

For instance, users may experience the sound of leaves rustling and the growling of a wild cat in a virtual jungle setting (as demonstrated in Google

Expeditions), which would articulate the feeling of being transported to a different realm, rather than perceiving it in the real world. In games like Beat Saber, rhythmic background music encourages players to engage physically by swinging their arms and hitting virtual targets, exhilarating their enjoyment and gradually immersing them in a virtual experience.

The tactile sensations are synthesised into a texture that becomes an essential element of an object, which then produces the force feedback. It fosters a sense of being immersed in a different environment (Sanchez-Vives & Slater, 2005). The feeling of encountering a solid boundary in a simulation, while receiving tactile feedback of a hand touching a solid wall, reinforces the connection between the real and virtual worlds.

Equipped with advanced headsets, users can effortlessly immerse themselves in realistic environments, exploring the captivating world of Virtual Reality. The research by Wang et al. (2024) creates an integrated system that uses multimodal haptic feedback to amplify users' embodiment of an avian avatar in VR through dedicated hardware components. The system aims to implement significant components of avian embodiment by mapping physical and virtual triggers. Still, there are issues concerning personalised avatars and the portrayal of tactile sensations (Wang et al.,2024). VR is well-suited for simulation-based learning due to its dynamic simulations that are graphically sophisticated and rendered in real-time. The focus is on improving visual detail, space awareness, volume perception, and depth perception to provide lifelike interactions, rather than relying solely on sensor-based interactions. This thesis is about virtual experiences, concentrating on visuals, not on tactile experiences, with no focus on wearable or haptic devices. This study aims to investigate virtual simulations and not peripheral physical devices.

2.4 Actional

Interactions within a virtual environment are multifaceted, enhancing the existing feelings and actions which are part of a digital realm. (Dede, 2009; Dede et al., 2017). For example, in Valve's Longbow, a virtual archery simulation, users may physically grab a bow and arrow, draw back the bowstring, and aim at dynamic targets. The player aims for the bullseye by pointing the bow and arrow and the length of draw determines the arrow's speed and is in direct relation to how fast the arrow is propelled during the draw. Presumably, the bow is drawn back in a realistic manner. After being released, the arrow takes a physics trajectory. When an application is responsive and appropriately developed, allowing for natural and smooth interactions within a virtual world, users become completely absorbed and unconscious of their surroundings.

- Visual: Exceptional visuals with precise motion tracking
- Audio: Acoustic stimuli
- Haptic and other technologies encompass tactile and force feedback mechanisms.
- Stimulates additional sensory perceptions
- Interactivity means the extent to which the user can control the system and how much the system responds to the user's actions.
- Actions: Pertinent physical bodily actions required to engage in and accomplish a chore.
- Roles: The role of a user and the importance of their actions.
- Contexts: A story illustrated in relevant and adequately significant environments.

Challenges offered to individuals give opportunities to improve their experience with better engagement and grasp. Social interaction refers to an exchange facilitated or influenced by technology or other forms of mediation. Initiation in a fictional realm with productive participation in activities within the digital environment (Dalgarno & Lee, 2010) are closely linked with two design elements: interaction and manifested motion. Interactivity or interactive interface design offers the user a greater degree of control and provides appropriate feedback (Roussou et al., 2006). In today's world, to preserve the natural interaction entered by the user, which is enabled by the Real-time motion tracking features, comprehends the body movement seamlessly (Sanchez et al., 2005; Slater, 2017).

A user's position and perception shifting between first and third person views is far more constraining than the process of interaction. A methodical review was conducted by Lui et al. (2023) on learning design theories that incorporate immersive virtual reality (VR) technology in science teaching. Their analysis emphasises that specific characteristics of immersive VR, such as interactivity, presence, and authentic simulation, enhance student engagement and comprehension, thereby facilitating better learning and understanding in scientific domains.

2.5 Story

The nature and features of the tasks engage learners and draw users' attention (Barab, et al., 2010). Methodising information to manifest the involvement in learning is a complex task, but it typically involves considering roles, settings, and obstacles in educational computer applications (Abdul et al., 2015; Barab et al., 2010). "Transformational play," a framework presented by Barab et al. (2010) views games as active agents that have an impact on meaningful narratives. Games promote deep learning through experiential engagement by fusing person, content, and context. During an immersive, life-changing educational experience, players make important decisions that relate academic material to real-world situations and foster critical thinking and identity development. Game-based learning in experiential pharmacy education is examined in the Dabbous et al. (2022) study. It evaluates educational outcomes, gauges student motivation, and validates a game-based tool (Dabbous et al., 2022).

Apprentices and even interns feel a sense of control and empowerment when they are given a specific role and meaningful work to accomplish. Virtual body ownership is a notable and fascinating aspect of VR and AR environments. It allows learners to assume the identity of another person and immerse themselves in a fictional universe (Slater, 2017). Following proper preparation, apprentices can engage in realistic simulations and undergo motion tracking to map their movements onto avatars. This enables them to step into various roles and truly understand the impact of their decisions. According to Jacobson (2017) and Yee &

Bailenson (2007), this strategy has proven effective in prompting participants to rethink leading hypotheses and modify their behaviours.

Storylines that are skilfully designed within relevant contexts have been found to be highly helpful in engaging learners in the process of learning, according to Abdul Jabbar and Felicia (2015). Alotaibi (2024) carried out a systematic review and meta-analysis on the use of games in teaching in early childhood education. Their findings revealed children benefited greatly in cognition, social and emotional development, motivation and engagement. The findings support game-based learning as a valuable, engaging educational tool for young learners. An example of this is the immersive experience offered by the virtual reality movie Allumette, which draws users in emotionally and fosters empathy toward the protagonist, an orphaned girl who suffers a sad event, but in the end, finds kindness and hope.

When educators strive to engage students intellectually and emotionally using academic utilities, it is crucial as it incorporates a captivating and meaningful narrative to contextualise learning and inspire apprentices to uplift their insights, abilities, and mindsets (Barab et al., 2010). Immersive Media apps can provide several levels of challenges and allow learners to make multiple efforts in order to align with their understanding and expertise. Bowman et al. (2024) conducted a study on video games and analogue role-playing games, providing curriculum developers with powerful methods for immersive and dynamic education. Transformational play theory defines play in which participants can take on the role of a main actor and make changes in systems and their lives, which provides the possibility of changing a fictional universe and the identity of a person, too. Also discussed the recent development of tabletop role-playing games for social and personal change and have provided insight on the idea of safety and reflection as design elements, which maximise the transformative potential in education.

2.6 Social

Positive social connections in a digital setting equip the learners to get involved in the virtual community, enabling them to participate in meaningful exchanges of ideas (Dede, 2009). Productive social interaction is an ideal stage in an apprenticeship for learners to articulate and reflect on concepts, enabling the sharing and criticism of their virtual space performance, which enhances the quality of their experience as well as knowledge acquisition processes (Dalgarno & Lee, 2010; Mikropoulos & Natsis, 2011). Productive social interactions in virtual spaces enabled apprentices to exchange feedback, thereby enhancing both the quality of their experiences and their knowledge building. Aspects like presence, autonomy, and natural semantics made virtual reality more engaging and conducive to immersive and contextual learning, leaning heavily on constructivist foundational theories. Overall, virtual reality in education enhances critical skill development (Cabrera-Duffaut et al., 2024). Fink et al. (2023) investigated 3D virtual environments' affordance by analysing authenticity and interest development in environments made through traditional 3D modelling techniques and those created through photogrammetry. Findings indicated that perceived authenticity did not differ significantly between the two groups.

Nonetheless, the level of interest in learning through VR increased following the intervention. Presence and initial interest emerged as primary predictors of interest after the intervention, highlighting the value of these factors in capitalising on the affordance of 3D virtual environments. Such interactions enhance the enjoyment and immersion in the educational process while simultaneously endeavouring to foster the learners in areas such as, but not limited to, information, verbal exchange, critique and analysis, and resolving challenges (Chen et al., 2018; Kinshuk et al., 2020). With the evolution of social and intelligent technologies, intelligent pedagogical agents gain greater relevance as they can provide immediate feedback and aid or tutor the learner. (Soliman & Guetl, 2010). The framework developed by Sorour et al. (2024) focuses on multi-smart agent systems with the goal of improving the effectiveness of 3D graphic production and aiding in the development of design thinking abilities in computer science educators at the elementary school level. The framework employs animated intelligent agents to facilitate cooperative and active learning. The findings of the experiment showed considerable enhancements in both cognitive and psychomotor skills. In addition, the article reviewed the application of intelligent pedagogical agents in teaching with virtual and augmented reality, explaining contemporary research trends and suggesting areas of focus for future research. Yin et al. (2018) analysed the development of intelligent pedagogical agents in the context of virtual and augmented reality learning environments and offered a thorough review of the especially concerning research trends and prospective developments.

2.7 Approach Taken for Conducting a Systematic Literature Review

2.7.1 Empirical studies are being searched for and selected

The authors adhered to the optimal reporting items for systematic reviews and meta-analyses (PRISMA) guidelines outlined by Page et al. (2021). The primary databases identified were Scopus, ProQuest, Web of Science, and Google Scholar. Scopus, ProQuest, and Web of Science are renowned databases that save scholarly publications across several academic fields. Google Scholar presents an impressive array of resources, featuring a diverse selection of articles, conference proceedings, and book chapters that cater to the needs of researchers and scholars.

To gather relevant studies that utilised immersive VR and included empirical data, a specific set of search terms was applied across three academic databases: Scopus, ProQuest, and Web of Science. The strategy that was used in this instance consisted of combining the following terms: “Immersive virtual reality” AND (education OR learning OR teaching) AND (participant OR student OR learner) AND (HMD OR headset). The author utilised a slightly modified search phrase since they were unable to generate a nested search term for Google Scholar. Using a succinct research technique, the most common word was picked from each pair of terms: person (participant, student, and learner) and obtaining information (education, learning, and teaching). Due to the minor similarities between the terms "headset" and "HMD" (head-mounted display), two independent searches were performed before being merged.

2.7.2 The participant in immersive virtual reality learning uses a Head-Mounted Display (HMD)

The search field was designed to include every text in the document. The document type was confined to full-text, peer-reviewed articles that were transcribed in English wherever possible. The coverage ran from 2016 until 2021. According to Google Search Trends, the popularity of virtual reality (VR) increased dramatically in 2016, with the release of highly anticipated VR headsets such as the HTC VIVE and Oculus Rift CV. Sherman and Craig (2018) report that this has resulted in an increase in the number of research publications conducted utilising VR headsets.

Zhou, Segura, Duval, John, and Isbister conducted research on mixed and augmented reality devices in 2019. Gold and Mahrer conducted studies in therapy, rehabilitation, and business in 2017, as did Tussyadiah, Wang, Jung, and Tom Dieck in 2018. Parsons conducted theoretical and secondary data analysis in 2016, but Pinter et al. produced application development reports without empirical findings in 2020. (Pinter et al., 2020)

2.8 Classification of the educational assignments

To analyse the academic exercises in VR and AR studies in terms of design features, this review used Merchant and colleagues' (2014) categorisation of learning tasks in the context of three types of educational computer applications: virtual world representations, simulations, and educational games. To gain a more comprehensive understanding of the educational activities, the study documented specific subject areas such as medicine, science, history, and design, as well as categorising the intended audience, which included primary school children, secondary school students, university students, and adults. An examination of the typical design characteristics found in educational Immersive Voice Response (IVR) studies. Several statistical analyses were undertaken to comprehend the implementation of different design characteristics in educational Immersive Media investigations.

2.9 Learning Theories

In the field of education, the integration of immersive technologies is significantly transforming the quality of learning experiences. Applications of AR and VR in educational settings align with various learning theories, such as Experiential theory, which emphasises the experience in sports by engaging and retaining students. Immersion virtual reality (VR) in teacher education was the subject of a systematic literature review by Billingsley et al. (2019). The study, which was published in the Journal of Interactive Learning Research, examines how virtual reality improves reflective practice, classroom management, and pedagogical abilities. The costing and easy accessibility issues still pose challenges. The theories in Constructivist Learning include: Emphasis on Self-Activeness in Students, through emotions, and through their environment (Meža et al., 2015). The interaction with the environment in all ways is important in learning, and immersive technology is now one such environment that fosters learning by nurturing creativity and engagement with real-world applications and other related concepts. Another fundamental learning theory is the Experiential Learning Theory, which is founded on the premise that learning is based on having experiences. Meža et al. (2015) mention that immersion learning emphasises the value of practice and reflection for knowledge acquisition in the first place. It also states that AR technologies based on the process of visualisation improve the understanding of board and abstract concepts practically. Ertmer and Newby (1993), in their research, proposed three main learning paradigms: behaviourism, cognitivism and constructivism.

Constructivism is an impactful learning theory based on experience that deeply influences the learning process. With an emphasis on hands-on learning, constructivism is an important guiding framework in education. Further on the same guideline, Abuhassna, H., et al. (2024) analysed various educational theories to guide instructional designers and educators in their application. Their research identifies important areas such as holistic learning environments, integrated systems, the use of educational robots in teaching, and improved schema assessment methods. This systematic review builds upon the existing body of knowledge and has the potential to shape educational practices in the future with the goal of optimising learning outcomes in diverse educational contexts (Abuhassna, H., et al., 2024). Where Kolb et al. (2014) assert that learners draw on their learned experiences to form knowledge through an in-depth interpretation of that experience, as visually depicted in Figure 2.1, this confirms Meža and others. Often, knowledge is formed in the process of schema development. Schemata are simply the representation of knowledge and its information processing objectives in contextual categories. Rahmi (2024) has reviewed the literature around Kolb's experiential learning theory and its four stages: experience, reflection, abstract conceptualisation, and active experimentation. The review showed that participation, active reflection, and the gradual build-up of theory provide students with a deeper understanding, sharpen their critical and creative skills, and better prepare them to tackle future challenges. The review also pointed out that the model is very useful in developing collaborative work skills and that it can be used at any level of education.

Immersive technology helps students learn by investigating and creating concepts. Active engagement in AR simulation of a construction site allows participation in engineering projects. Cognitive load is defined as the mental work needed to process specific information in the context of immersive media. VR, AR, and MR technologies offer users a multitude of auditory, visual, spatial, and interactive stimulation, which is far more than what traditional screens offer. Immersive media balancing experiences and aligning them to users' cognitive load is critical to ensure effectiveness. Balanced experiences can enhance learning, engagement, meaningful interactions, and aid in the retention of information. On the other hand, poorly designed experiences and poorly balanced cognitive demands can risk overwhelming, confusing, or fatiguing users. This, in turn, negates the intended benefits. Thus, without proper balancing of mental effort, users do not get the effectiveness and benefits of the technology provided. It is vital to consider the relationship between immersive technologies and cognitive load to aid in effective design. Such an approach allows focusing on learning needs without overwhelming the users. (Craig & Kay, 2023).

Cognitive Load theory argues that effective design of instruction is one which substantially reduces cognitive load and adds extra load to fit within the bounds of limited working memory resources availability (Midak et al., 2021). It is believed that augmented reality applications improve the burden of processing information as they offer visually encouraging information and place the information outside the scope of cognition. It is beneficial to adopt immersive technology in chemistry education to illustrate key concepts. This is also supported by cognitive load theory, which asserts the effectiveness of immersive technology in education for quality improvement and study support. Bloom's original taxonomy was revised by Anderson and Krathwohl (2001) to better reflect contemporary educational practices. The cognitive domain was reformed into a two-dimensional model consisting of knowledge types and a cognitive process taxonomy. Active learning was included in the updated version of Bloom’s taxonomy by emphasising verbs in

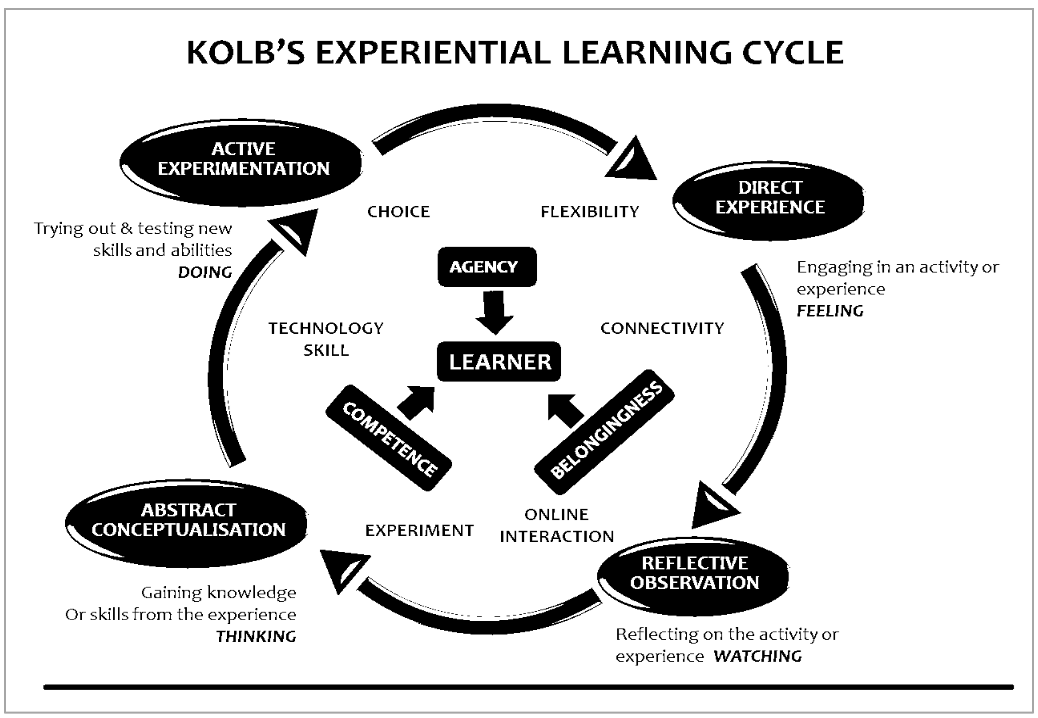


Figure 2.1 A framework that integrates Carver et al. (2007) and Kolb's theoretical learning cycle. (Source: Author’s own creation)

place of nouns, with a focus on the cognitive processes of remembering, understanding, applying, analysing, evaluating, and creating. This update allowed for the purposeful planning of instruction, assessment, and curriculum tailored to today's learning goals. Furthermore, the study has been explored in additional dimensions. Demir (2024) proposed a model for integrating social media platforms into classrooms to benefit university lecturers and students, which enhances learning outcomes. It introduced a Web 2.0 social media taxonomy based on three dimensions—Consciousness, Cognition, and Creativity (3C)—to streamline teaching, learning, and evaluation to meet curriculum benchmarks. The proposed taxonomy highlights the significant role of social media in enhancing and facilitating collaboration, communication skills, and even critical thinking in education (Demir, 2024) . The taxonomy organised instructional goals in a funnel from lower to higher-order thinking, thereby helping students attain mastery and 21st-century competencies across basic to advanced learning stages.

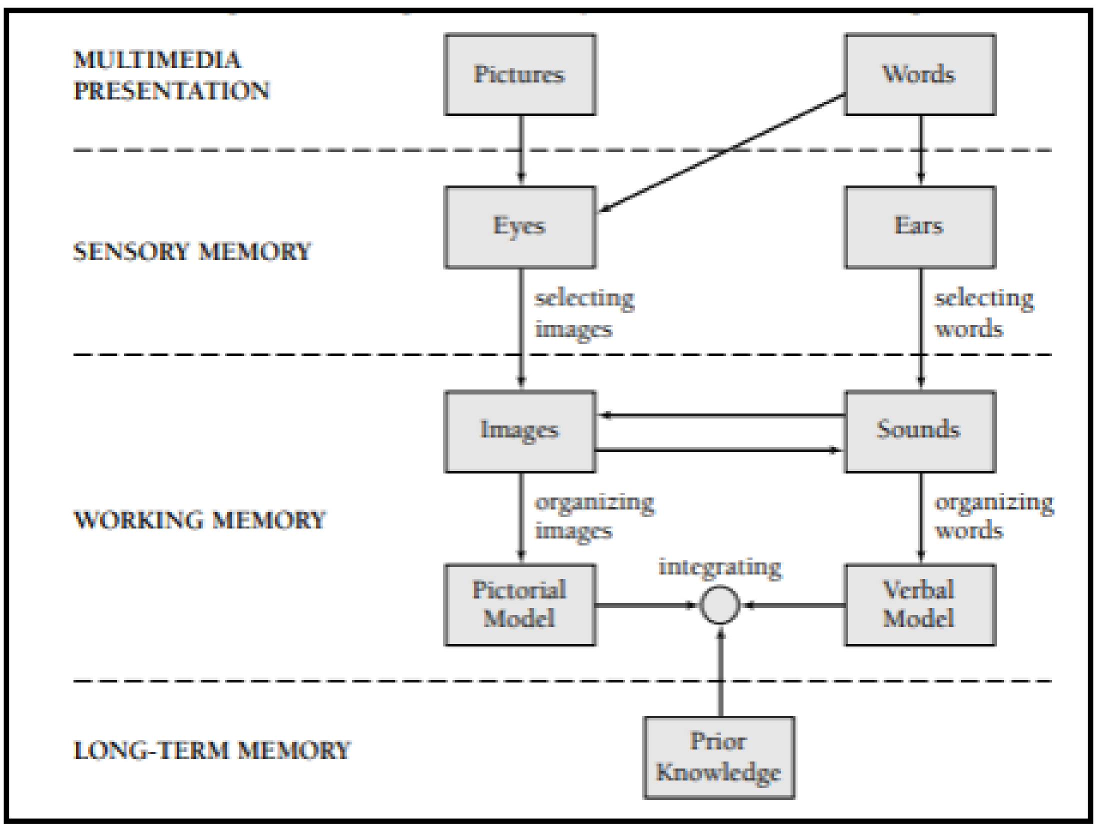


Figure 2.2 Cognitive Psychology (Source: Mayer et al., 2002).

2.10 Cognitive Psychology

Immersion is made better because of some principles from cognitive psychology, such as memory, attention, and problem solving, and also, learning is significantly improved as immersion captures the attention of learners quite easily (Sampaio et al., 2010). Such a type of interactive technology encourages active and deep thinking as they control cogs of loads, and that promotes learning (Dorta et al, 2011). According to Mayer et al. (2002), cognitive psychology views emotional intelligence as distinct from IQ, comprising mental skills for processing, understanding, and regulating emotions. From the educational point of view, it encourages constructive ideas as it increases motivation and allows active and social engagement with knowledge concepts. Likewise, contextualization of knowledge is embedded in the provided technology as it supports situated learning theory in efficiently creating real-life knowledge if used (Figure 2.2). In their 2019 study, Aksnes et al. examine how citations and citation indicators represent the calibre of research, focusing on the social and cognitive elements that affect citation patterns. Citations act as stand-ins for impact, but they are influenced by biases like visibility, prestige, and disciplinary standards. Citation patterns are also influenced by cognitive elements, such as the novelty and relevance of the research (Aksnes et al.,2019).

2.11 Design Education

The process of design education is continuous and includes different views perspectives. In a traditional view of design education, what is taught is centred on basic skills, production methods and the established rules of design. Proponents of this point of view advocate for an orderly scheme of courses built around specific knowledge and the acquisition of skills, as well as the comprehension of design principles (Sampaio et al., 2010). As Mendoza-Ramírez et al. (2023) reported, augmented reality (AR) is a technology that augments someone's view of the physical world with computer-generated images, sounds, or text. Their survey offered a comprehensive understanding of AR's limitations, its challenges in practical use, and its most important fields of application within and outside engineering. This literature review gained a strong understanding of AR technologies and their advanced applications, especially their advanced techniques, potential use, and the obstacles to their widespread application, listing future research and development challenges in the ever-developing field of augmented reality (Mendoza-Ramírez et al., 2023).

Design education is composed of lectures, studio teaching and student critic sessions under the guidance of mentors. In fact, there are increasing difficulties in implementing the traditional processes of design education due to the evolution of the environment in which the students are operating. These traditional processes have stifled innovation and hindered learning (Dorta et al., 2011). In contrast, developing the educational process is based on students and covers them during the educational process. The focus of this particular learning approach is to bring out innovative concepts of how to learn, which emphasises the experimentation process, problem-solving insights, and other key aspects. In addition, this process focuses on the strategy of project-based learning, which enhances other learning processes.

With regard to the two styles of learning, there exist vast disparities that enhance the learning process for the students. With the use of progressive techniques, the focus is on flexibility and creativity in the overall learning design. Though the overarching goal of traditional education is to develop skills and establish design principles (Dorta et al., 2011). On the other hand, progressive education might allow students to opt for self-directed ways of learning from different aspects, whereas the traditional system may present a more guided approach with set criteria for learning and evaluation. One of the cases provided above states that progressive learning allows for the development of student-centred processes in the learning environment and helps mould the students. Based on this literature analysis, the implementation of immersive technology in design education benefits from progressive learning concepts.

2.12 Immersive Technology/ AI tool

In educational procedures, the integration of immersive technology helps achieve significant improvements in transforming learning processes. The incorporation of AR and VR into education has created engaging learning environments for individuals. Immersive environments that provide students with practical exposure and real experiences have been reported to increase participation, improve retention of information, and support the successful understanding of complex concepts (Venkatesan et al., 2021). Additionally, immersion technology has been shown to boost involvement by offering customised learning tailored to students. Immersive technology enhances education due to its advantages. However, there are some limitations, particularly regarding initial development and resource requirements. In the field of immersive technology, it is safe to say that a computer and its associated software are highly effective. Therefore, access to this learning approach may be regarded as somewhat challenging. From the discussion above, the following questions arise: What are students' attitudes towards using such sophisticated new technologies? How does the integration of these technologies influence the educational process in design? These questions can be extended by exploring other related issues concerning the role of technology in present-day learning. One approach aims to broadly address ethics, overcome technological barriers, and implement these technologies effectively for educational purposes.

2.13 Muscle Computer Interface

A wide range of well-established human-computer interaction (HCI) technologies exists today. Among the various stages of HCI development, studies on brain-computer interfaces (BCI) are particularly highly regarded. These devices can significantly surpass human limits by supporting, enhancing, or restoring cognitive and sensory-motor functions, among other capabilities (Chowdhury et al., 2013). There has been growing interest in Muscle Computer Interfaces (muCIs) as a new modality of interaction within HCI. A muscular computer interface refers to a technology that enables users to operate devices through muscular electrical signals. In simple terms, it allows users to utilise their myoelectrical signals to control devices.

Table 2.1 showing some of the important literature surveyed in this thesis that highlighting the inferences

Categorised Domains	**Findings**	**Inferences**	**Gap**	Related Journals
Learning Theories 4o papers studied	Principles of fundamentals of learning, Experiential learning	Learning theories help to increase engagement and understanding	Limitations related to Design education	(Kolb et al., 2014), (Chowdhury A. 2019) (Kothari et al., 2004), (Sampaio et al., 2010). Sharma and Kumar (2024). (Rahmi, 2024)
Cognitive Psychology / Pedagogy 35 papers studied	Experiential learning versus cognitive load	Especially, learning has to be cohesive	Cognitive inferences, Design psychology, looking into human behaviour	(Kaplan et al., 2021), (Thomas, Tuteja and Chowdhury, 2021), (Meža et al., 2015), (Dorta et al., 2011), (Von et al., 2022)
Design Education 30 papers studied	Design pedagogy needs to be tailored to meet the needs of students.	There is a lack of association to look into pedagogy. Many Design institutes are mushrooming, but there is a lack of technology use for teaching purposes.	Need to create awareness about technology to use as an aid.	(Guan et al., 2021), (Venkatesan et al., 2021). (Mohamed & Sicklinger, 2022), (Choi et al. 2018), Huang and Lee (2022)
Immersive Technology/ AI tool 50 papers studied	The analysis of the responses to the open-ended subject matter shows that there were significantly better responses in the virtual reality activity than in the physical activity.	Augmented Reality empowers the ability to visualise in the real world. The AR objects can be placed, rotated, and scaled as per the user's convenience.	Dirt of Papers on Design education. There is mostly literature available on Medical, Architecture, or Civil engineering, etc.	(Kee et al., 2023), (Arce et al., 2022), Silva et al. (2022), (Wohlin & Aurum, 2015), (Pribeanu et al., 2017). (Moro et al. 2017), (Mazhar et al., 2021), (Bernardo et al., 2022), (Camba et al., 2017), (Evans & Söderlund, 2021).
	Provides a detailed discussion of relevant literature on the application of AR in teaching sciences. Notes are made that there are a few studies with a view to evaluating innovative AR-related learning.	Identifies the research gaps and proposes the research questions, including the need to look deeper into the learning experience, which has hardly been touched on elsewhere.		(Chen & Teh, 2013)

	The authors report on a field study conducted with AR and one with 50 students of electrical engineering in the context of higher education.	The research indicates that AR enhances learners' satisfaction with their approach to the content.		(Martín-Gutiérrez, Fabiani, Benesova, Meneses, & Mora, 2015)
	A systematic review was conducted to examine experimental studies published since 2013 that compared quantitative learning outcomes using HMD-based I-VR to less immersive pedagogical methods, such as desktop computers and slideshows	The paper underscores the importance of a systematic approach to the problem, highlighting the need to determine what and how to assess, the nature of the interventions, and the learning objectives as key to harnessing Interactive VR as an instructional tool.		Yammiy Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021).

Impulses are used to control various devices and gadgets. While the term muscle-computer interface may seem relatively new, the concept of myoelectric devices containing surface electromyography electrodes has been in use for a considerable period of time. Electromyography signals have been successfully applied in the past within a number of industries, including medical (Wang et al., 2022).

Following this, academics have researched and discussed ways to enhance these interfaces' usability and affordability while developing armbands that are easy to wear without sticky gel. Saponas et al. highlighted additional valuable applications of muCI, noting that the system works effectively without needing constant recalibration when worn and removed (Saponas et al., 2009).

2.14 Findings and Research Gap

There aren't many research studies or resources that discuss the application of emerging technologies in design education. There is some available literature that concerns the research on the applications of Virtual Reality and Augmented Reality in the field of architecture, K-12 education, engineering, and construction, including Medical Science. The research gap has been identified because there has been no such research focused on the use of immersive technology in education

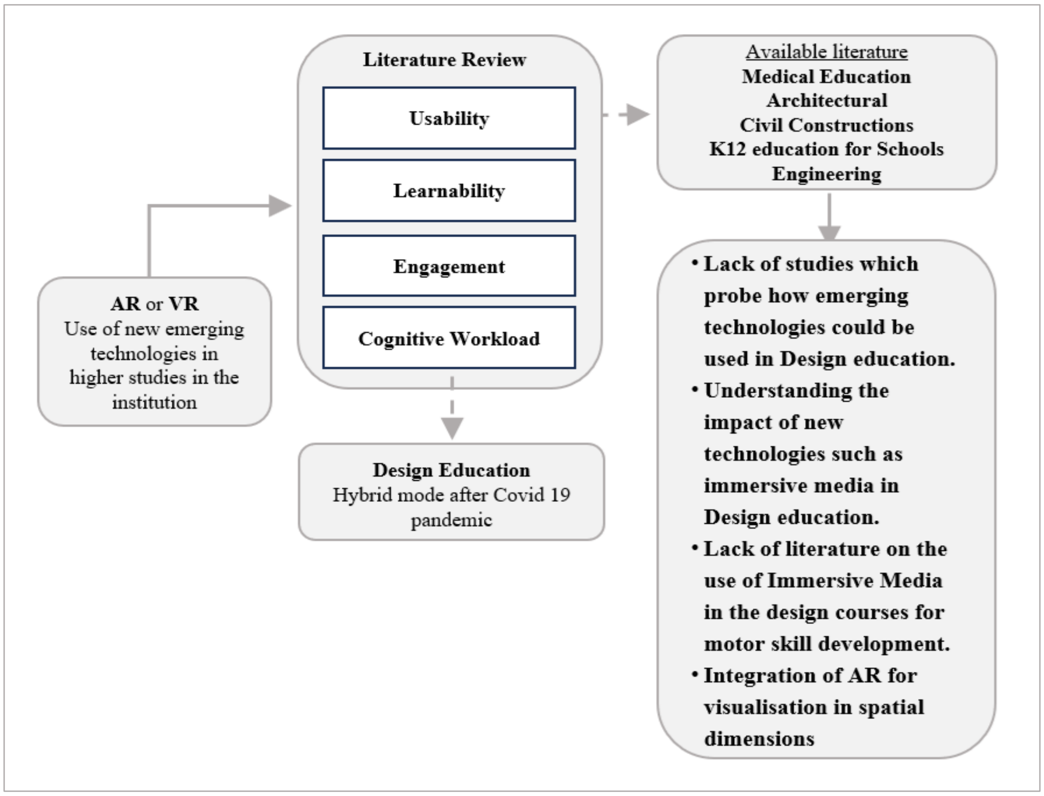


Figure 2.3 Research Gap of the Literature Survey (Source: Author's own creation)

This study reveals a significant research gap due to the lack of literature on the application of immersive media in design education. The main research gaps include issues related to inclusion, accessibility, and the effect of fully integrating immersive technologies on student engagement. Further research is necessary to develop guidelines for the appropriate use of such environments for learning and to address moral considerations associated with these contexts. Refer to Figure 2.3.

2.15 The research questions of the thesis

Based on the research gaps identified in the Literature Review, the following fundamental research questions were developed to be investigated in this thesis:

RQ 1: How will Immersive Media (VR & AR) concepts enhance 3D model-making among industrial design learners in design education?

RQ 2: Can VR-based instruction be more efficient than conventional 3D software in 3D model making for industrial design learners in design education?

RQ 3: How does the use of Immersive Media, such as Augmented Reality (AR) technology, impact the learning process of industrial design students in the context of 3D model making?

RQ 4: Does prior experience with immersive media technology gadgets influence learner engagement when using an AR application for 3D model-making in industrial design?

RQ 5: Does cognitive workload influence learner engagement while using an AR application to learn 3D model-making?

2.16 Aim and Objectives

This thesis seeks to explore how immersive media technologies, specifically Virtual Reality (VR) and Augmented Reality (AR), can improve learning engagement for industrial design students in the context of developing 3D model visualisation. It will compare the effectiveness of these technologies with traditional teaching methods in model-making education.

Objectives of this thesis are:

a) To study Immersive media (VR & AR) concepts that will enhance 3D model-making among industrial design learners in design education.
b) To investigate the use of VR that is more efficient than conventional 3D software in 3D model making for industrial design learners in design education.
c) To identify the factors that influence learner engagement while using an AR application for 3D model-making in industrial design education.
d) To investigate the impact of cognitive workload on learner engagement while using the AR application for 3D model making.
e) To explore the effect of usability that influences increased engagement while using AR applications to learn 3D model making.
f) To investigate to compare the efficacy of the use of VR and AR in model making in industrial design education.

2.17 Key take-away

An increasing number of educational scholars are exploring the viability and possibilities of Immersive Media for educational purposes. While several empirical studies have shown that students generally have a positive view of -based learning, there is still uncertainty regarding the specific factors that contribute to its effectiveness and how academic Scholars effectively utilise its distinctive qualities of Immersive Media. This systematic study seeks to address the gap in the literature regarding the preconceptions educational researchers employ when creating immersive learning environments in recent studies. This study utilised Dede's (2009; 2017) immersive interface design as a basis to record several designs of educational applications.

This review further expands and modifies the design to integrate both technological and pedagogical elements. Out of 219 empirical studies published from 2016 to 2021, this review found that technical features, such as high-quality images and interactive interfaces, were commonly used to enhance the sense of physical presence. In contrast, instructional components such as contextualisation and social interactions, which contribute to learners' engagement, were not often observed. Additional clustering analysis indicated that the limited integration of educational elements did not suggest a greater emphasis on technology over pedagogical aspects by academics. Instead, our analysis showed that researchers included multiple variations of design features based on their educational goals, priorities, and environmental constraints, as integrating all design aspects could be costly and time-consuming. This review identified five prevalent strategies for building-based learning activities. Unlike existing comprehensive literature on educational research, this review effectively demonstrates various methods used in constructing such learning approaches.

3 Chapter 3. Research Methodology

Chapter Summary: A fundamental component of scientific investigation is the hypothetico-deductive method, which enables investigators to develop hypotheses and evaluate them by methodical observation and experimentation. This method offers a structured framework for investigating complex educational phenomena within the field of design studies, specifically with respect to the potency of immersive media in improving 3D model-making among learners of industrial design. The application of the hypothetico-deductive approach to analyse the influence of immersive media on the process of design education will be covered in this essay, with particular attention paid to the development of hypotheses, planning and execution of experiments, and the analysis of findings.

Keywords – Hypothesis, Immersive Media, Research Design, Research Methodology.

3.1 Study Process

3.1.1 Establishing the research problem:

There are two categories of research problems: those about natural states and those about changeable connections. To begin a research project, researchers must identify a problem or feature of a subject that they wish to investigate. To begin, describe the situation broadly and then clarify any uncertainties. Before creating a functioning issue formulation, it's important to assess the practicality of the proposed solution. The initial stage in scientific inquiry is to break down a broad topic into an explicit problem. Formulating a research problem involves two steps: properly grasping the problem and rephrasing it in analytical terms (Kumari et al., 2023; Likwa & Mweenda, 2019; Pandey & Pandey, 2021).

To gain a better understanding, consult with colleagues or experts in the field. In academic institutions, researchers might seek assistance from experienced guides with specific study concerns in mind. When guidance is needed to research a subject, one consults colleagues or experts in the field. To some extent, guides or other qualified personnel are essential for research at academic institutions. Guides should focus on overcoming particular research problems. Such problems are often vague in nature, as perceived by the guide, which recommends that the researcher specify them in practical terms. In private units of companies or public organisations, such problems are formulated by managers and administrative personnel. Such explorations can include the context of the problem and investigate possible solutions.

3.1.2 Comprehensive literature review analysis and inferences

After the problem has been put across in the most measurable way possible, the next step should be to prepare a report. The research scholar pursuing a PhD program has to write a problem statement and seek its approval from the concerned Committee or Research Board.

At this stage, the researcher has to provide an in-depth literature review regarding the topic (Mohamed Shaffril, Samsuddin, & Abu Samah, 2021). For this purpose, first of all, the main tools to be employed will be analyses and indices of journals as well as published and unpublished bibliographies available online or in print. It is significant that academic periodicals, conference papers, state documents and books are used depending on the nature of the problem. It is worthwhile to mention that in this chain of events, one source yields another one. If the sources match those of present research, then past research, if any, should be evaluated with extreme care. At this point, a good library would help the researcher quite a lot as well.

3.2 Develop working hypotheses

After doing a thorough literature review, researchers should clearly explain their hypothesis(es) (Casula, Rangarajan, & Shields, 2021). For lack of a better term, a working hypothesis can breeze through many dimensions. It is a Great idea as it combines a variety of topics into one great idea. To be tested, hypotheses should be precise and relevant to the study topic at hand. The hypothesis defines the study field and keeps the researcher on track. It sharpens his thoughts and concentrates on the most significant aspects of the situation. Additionally, it specifies the necessary data and analytic procedures.

How do you go about constructing working hypotheses? The answer is to follow the following rationale:

To solve a problem, follow these steps: (a) Discuss it with colleagues and experts; (b) Examine available data and records for trends and clues; (c) Review related studies; and (d) Conduct exploratory interviews with interested parties and individuals.

3.3 Hypotheses Testing Rules

In hypothesis testing, we use a decision rule to determine whether to accept or reject a hypothesis (H_0 or H_a) (Kothari, 2004). For example, if H0 posits that a specific lot is acceptable (containing minimal faulty goods) vs Ha, which asserts that the lot is unacceptable (containing excessive defective items), it is necessary to determine the quantity of things to be tested and the criteria for accepting or rejecting the hypothesis. We may evaluate 10 items from the lot and determine our judgment based on the criterion that if there is none or just one defective item among the 10, we will accept H0; otherwise, we will reject H0 (or accept Ha). This type of foundation is referred to as a decision rule. Kothari (2004) provided a broad, foundational guide to research methodology that spanned both quantitative and qualitative paradigms. His work systematically addressed research design, data collection, sampling, hypothesis testing, and statistical analysis, establishing a methodological backbone applicable to various disciplines.

An augmented reality (AR) system was created and assessed by Tiwari et al. (2024) in order to improve learning in an engineering drawing course. They created the AR intervention, established goals, and tested it empirically with students using experimental methodology that complied with Kothari's research design principles. Pre- and post-tests were used in the data collection process, and learning gains were then evaluated through statistical analysis. Kothari's methodical approach—problem identification, hypothesis framing, tool design, and result evaluation—is exemplified in this study, which shows how AR can enhance visualisation and comprehension.

3.4 Hypothesis-testing

We have performed various inferential statistics for hypothesis testing, including the chi-square test, Mann-Whitney U test, Z-test, One-way ANOVA, and F-test. Depending on the study topic, hypotheses can be assessed using different tests. Hypothesis testing determines whether a hypothesis is accepted or rejected. If a researcher does not have hypotheses, generalisations based on facts might serve as hypotheses for future studies.

Chi-Square Test in VR & AR

Definition:

In cases of user studies involving VR and AR, the Chi-Square test is a unique way of measuring user interaction and perception since it assesses the association between two categorical variables. (Cáceres et al., 2024)

Assumptions:

- only whole values, counts, must make up the dataset.
- Categories must be exclusive and mutually exclusive; therefore, a single comparison is applicable.
- Every observation and the sampling process must be independent, and random sampling is encouraged.
- At least 80 percent of the cells must have a projected count of five.
- A certain threshold must be met in regards to the sample considered for the analysis. (Levine & Stephan, 2022)

Mann-Whitney U Test in VR & AR

Definition:

In the context of VR and AR, the Mann-Whitney U Test is arguably one of the most important non-parametric tests as it looks deeply into two independent groups and determines if the distribution of the data differs in ordinal or continuous form. (De Lorenzis et al., 2024)

Key Assumptions:

- Each group must have normally distributed residuals for the test to be valid.
- Equal variance is also a very essential criterion for strong comparability between the groups.
- Each observation must be distinct from the other.
- The dependent variable, as the subject of impact measurement, must have been precisely measured in a continuous metric.

One Way Anova in VR & AR

Definition:

One-way ANOVA is a test that aims to identify the most significant differences in the average values of the dependent variable among three or more independent groups caused by one factor. It is an important statistical tool used in VR and AR based research.

Assumptions:

- Samples must be independent. Overlapping among participants in different groups must be avoided. This strengthens the credibility of the research outcomes.
- The outcome variable must be ordinal or continuous to enable in-depth analysis.
- Analysis is most clear when conducted on two independent, non-interacting, categorical conditions. (Mishra et al., 2019) • The distributions do not have to be the same, but must show some degree of homogeneity in shape.
- It is essential that the sampling of participants be random and representative in order to achieve reliable, valid, and generalisable results.

3.5 Formulating the research design

Once the research topic is clearly defined, the researcher must develop a research plan, outlining the theoretical framework for the study. Creating such a plan improves research efficiency, leading to the maximisation of information gained (Tomaszewski, Zarestky, & Gonzalez, 2020). The purpose of the study plan is to enable the collection of relevant evidence while minimising the strategic use of effort, time, and financial resources. Achieving this largely depends on the research objective. Ultimately, the success of these efforts depends on the research focus. Research aims can be grouped into four main categories: (i) Exploratory, (ii) Descriptive, (iii) Causal, and (iv) Action. When the research aim is exploratory, a relatively flexible research design that allows for examining various aspects of a problem is suitable.

However, the three designs may be separated into two categories: experimental or hypothesis generation, and exploratory or non-experimental hypothesis testing. Informal designs can be either non-equivalent (before and after a treatment, after a treatment only, before and after a treatment) or formal (completely randomised design, randomised block design, Latin square design, simple and complex factorial designs), and the researcher must choose a design to structure their study and draw valid conclusions.

The statements on the design of a research study usually outline step-by-step how a study crafted for a specific problem will achieve certain objectives while also highlighting particular features: (i) strategies and techniques for collecting data; (ii) characteristics of the researchers and other assistants; (iii) the basis for the structure of the chosen data collection methods; (iv) the duration allocated for the study; and (v) cost estimates for the entire project.

3.6 Determining sample design

To determine the sample design, examine the entire 'universe' or 'population' of items in a specific field of investigation (Lohr, 2021). A census study involves counting all items in the population. When every element is included in an inquiry, there is no margin for error, leading to maximum accuracy. However, in practice, this is often not possible. As the number of observations increases, even minor biases become more apparent. Moreover, bias cannot be identified without conducting a resurvey or performing sample checks. Additionally, this kind of study requires considerable time, money, and effort. Furthermore, census inquiries are frequently impractical in many situations. Blood testing, for instance, is often performed on a sample basis. Generally, we select a limited number of objects from the universe to investigate. These selected items constitute a sample.

3.7 Data collection

When solving real-world problems, it's important to acquire relevant data. Data collection methods vary depending on the researcher's budget, time constraints, and available resources (Taherdoost, 2021).

Primary data is usually obtained by conducting experiments or surveying people. So, when a researcher conducts the experiment and gathers quantitative measures, the validity of the hypothesis can be tested. In surveys, data can be acquired using several methods, including:

(i) (i) By observation: This type of study is based on collecting primary and fresh information because the investigator does not interrogate respondents. The information obtained is new and is not based on any previous behaviour, intentions, or attitudes of the respondents. It is costly and provides limited information, but it is not ideal when used with large samples of queries.

(ii) Personal interviews: The investigator uses a structured approach to answer pre-determined questions. This organised data collection strategy relies heavily on the interviewer's abilities.

(iii) Telephone interviews: This approach collects information by calling respondents over the phone. Although not commonly utilised, this approach is crucial for industrial surveys in developed nations, especially when time is of the essence.

(iv) (iv) Mailing questionnaires: This survey technique involves direct communication between the researcher and respondents. Respondents are sent questionnaires by mail and asked to return them once completed. This method is commonly used for economic surveys, business surveys, and similar research. After conducting a pilot study, it helps identify weaknesses in the questionnaire before implementing this method. A questionnaire-based survey requires careful preparation to facilitate effective data collection. Kim and Rhiu (2024) propose and validate a specific usability scale for VR systems that is based on traditional heuristic evaluation techniques. To ensure validity and reliability, further testing on different VR platforms is necessary. It is anticipated that the scale will be widely adopted as a more effective and dependable tool for evaluating perceived usability in VR (Kim & Rhiu, 2024).

(v) Using schedules: This approach involves the appointment and training of enumerators.

They are given schedules with appropriate questions. The enumerators provide respondents with schedules. To gather data, enumerators fill up schedules based on respondents' responses. This approach relies heavily on the enumerator's capabilities. Conducting field inspections on enumerators may guarantee they are doing their job correctly.

3.8 Project execution

This is a vital part of the research process. Proper project implementation ensures accurate and dependable data collection. The researcher is accountable for guaranteeing timely and systematic project execution (Ingason & Jonasson, 2019). Structured questions facilitate easy machine processing of survey data. In this context, both questions and likely responses can be programmed. To gather data through interviews, ensure proper interviewer selection and training. Interviewers might undergo training using instruction manuals that clearly outline their roles at each stage. Conduct field inspections to confirm interviewers are performing their duties effectively.

To ensure a realistic survey, monitor for unexpected circumstances. To guarantee accuracy, survey data should be statistically controlled to meet predefined standards. To manage non-cooperation among respondents, effective measures should be devised. To handle non-response, compile a list of non-respondents and choose a small sample size.

3.9 Data Analysis

After collecting data, the researcher proceeds to the analysis stage. The data analysis involves several interconnected steps, such as creating categories, coding raw data based on these categories, and later conducting statistical generalisation (Peck et al., 2020). The preliminary analysis aims to merge different variables into several functional groups and tables for easier future analysis. Therefore, researchers make a rough classification of the raw data to help it gain meaning. This step often also includes the coding process, which converts data categories (representing analysis units) into nominative forms that are simpler to count and tabulate. Editing is the stage that enhances data quality for coding. The coding process has already prepared the data for tabulation.

3.10 Strategies for Design of Experiments in this Thesis Work

3.10.1 Scenario-based enquiry

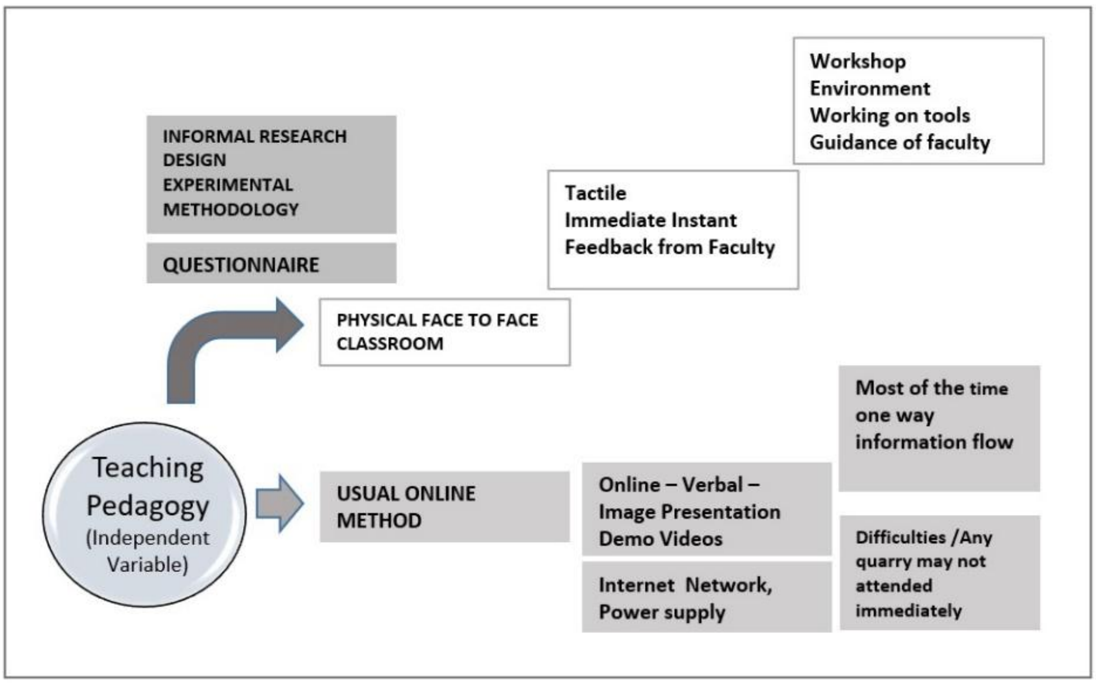


Figure 3.1. Initial understanding of the scenarios. (Source: author's own creation)

To address the research gaps and questions outlined in Chapter 2, a scenario-based survey has been planned. This includes conducting an initial survey with design students, supplemented by observations and informal interviews with a focus group comprising students and design faculties. The aim is to identify the subjects that students find most challenging to understand in an online learning environment. See Figure 3.1.

3.11 Sample Selection:

To ensure diversity in skill levels, learning styles, and prior exposure to technology, a varied group of industrial design students should be chosen. Students from various design educational backgrounds and at various stages of their design education should ideally be represented in the sample. In the study, only the design students with prior 3D software knowledge were considered.

3.12 Control and Experimental Groups:

Participants are divided into two groups: a control group using conventional tools such as 2D sketching and CAD software, and an experimental group using immersive media (VR/AR). The results can be directly compared within this setup.

3.13 Measures Taken Before and After the Test:

It is advisable to conduct pre-tests to assess baseline 3D skills for evaluating the effectiveness of immersive media. A post-test should be conducted after a structured learning intervention that incorporates immersive media for the experimental group. These may include tasks that assess technical skills (accuracy, complexity) as well as creative qualities (originality, aesthetics).

3.14 Qualitative Feedback:

Focus groups and interviews are also used to gather qualitative information alongside quantitative assessment. Such inquiries may include areas of concern, benefits realised from immersive media, and student engagement. This triangulation of methods provides a broad understanding of the effect on education.

3.15 General Methods for Analysis of Data

The analysis of the data follows once it has been collected. Statistical techniques like ANOVA and t-tests are useful for determining if there are significant differences between experimental and control groups when analysing quantitative data. If hypothesis H1 is confirmed, it is expected that the experimental group will perform better than the control group in both accuracy and creativity in their 3D models. The process of coding responses to identify recurring themes and insights is known as qualitative data analysis. This may show the effectiveness of immersive media as well as how it influences students' views on problem-solving, design, and teamwork.

3.16 Research Framework

3.16.1 Inductive and Deductive Approach

In the research process, two types of research approaches are used to conduct the study: inductive and deductive research approaches (Proudfoot, 2023). Regarding this study, a hypothetical deductive model is applied to carry out the research. This method was pioneered by Base, who identified topics, developed a research hypothesis, conducted the research, and later analysed the data and presented the findings. This enables researchers to perform experiments that test the hypotheses they have formulated about broader theories. Using this approach, results, along with their analysis and interpretations based on a specific hypothesis, were obtained.

3.16.2 Sample Size and Sampling Technique

The study used various sampling techniques, but the lifetime sample had to be fully exhausted and sampled without replacement, as required. Purposeful sampling methods were employed to advance the aims of the study in line with previous literature (Mweshi & Sakyi, 2020). This involved recruiting students at different stages of their education, including those from various bachelor’s and master’s level design programmes. Most participants were 22 years old and included both males and females. Such a method reduces bias and improves the representativeness of the study by giving all units in the population an equal chance of being selected. Additionally, non-probability sampling helps in obtaining unbiased samples, which facilitates in-depth investigations into immersive technology in design education, model refinement, and data collection (see Figure 3.2). There are primary and secondary types of data, which are systematically

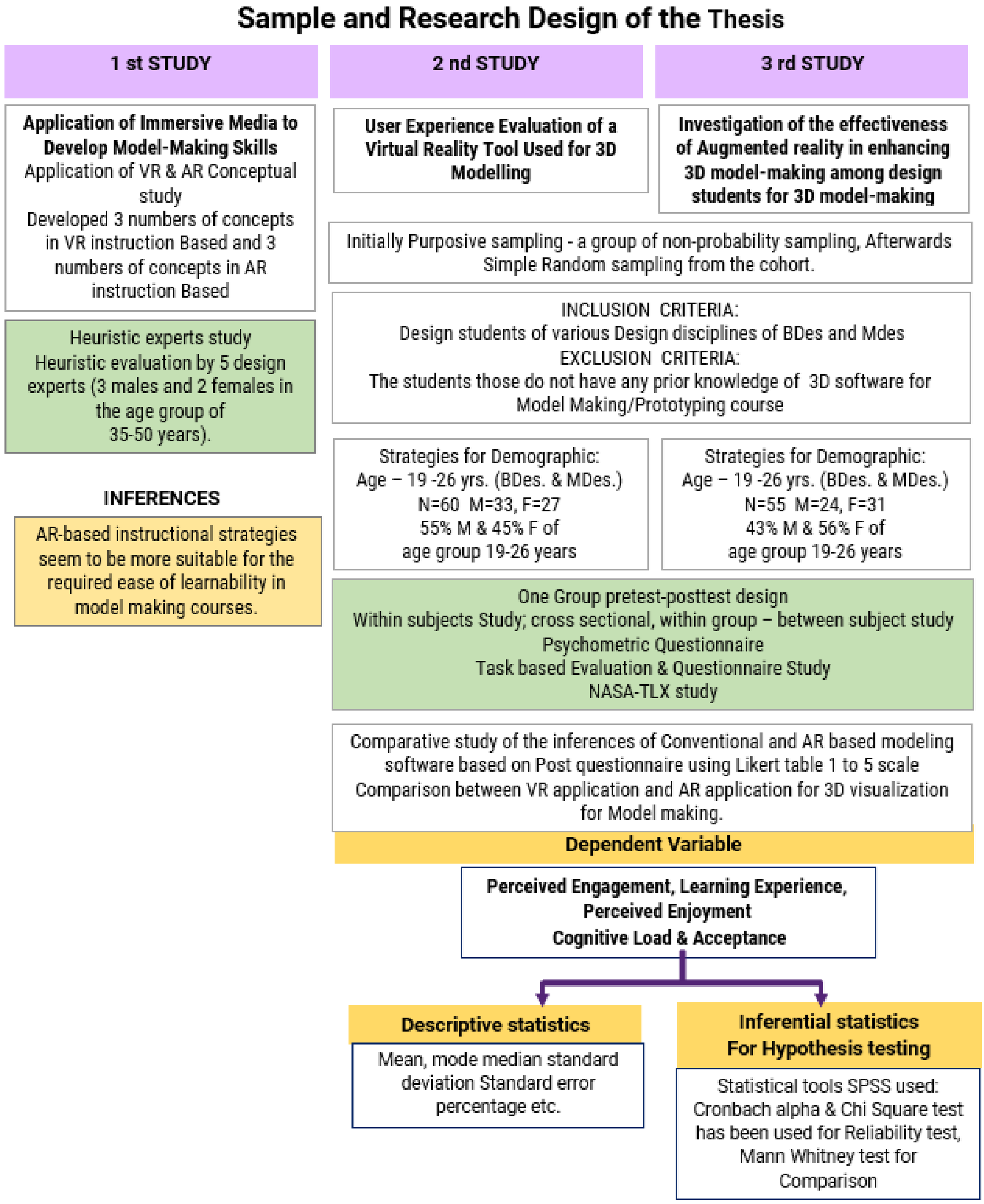


Figure 3.2 Research Design Framework – Three experimental design stages Pretest and Post-test study (source: Author's own creation)

organised. The primary data collection process starts from gathering basic/background information necessary for the study's objectives. This includes online surveys evaluating students' outcomes and interactions with the immersive technology, and their responses to both closed- and open-ended questions (Mazhar et al., 2021). Qualitative responses to semi-structured interviews on various technologies and their impacts on education processes also form primary data.

3.17 Hypotheses

Null Hypothesis (H_0): There is no significant difference in the level of learning engagement between industrial design students who use Immersive media such as Augmented Reality (AR) instead of traditional CAD software to learn 3D model creation.

Working Hypotheses:

H1: Industrial design learners using VR App for 3D model-making will exhibit significantly higher levels of learning engagement, perceived ease of use, enjoyment and lower levels of cognitive workload in comparison to those using conventional 3D software.

H2: Industrial design learners using AR App for 3D model-making will exhibit significantly higher levels of learning engagement, perceived ease of use, enjoyment and lower levels of cognitive workload in comparison to those using conventional 3D software.

H3: Industrial design learners using the AR App for 3D model-making will exhibit significantly higher levels of learning engagement, perceived ease of use, enjoyment and lower levels of cognitive workload in comparison to those using the VR App.

H4: In comparison to the use of VR, industrial design learners using AR technology for 3D model-making will exhibit higher levels of learning engagement.

3.18 Study Design

The research methods used in this project include a one-group pretest-posttest design. In this approach, all respondents first undergo a preliminary evaluation aimed at gaining an in-depth understanding of the use of immersive technology in design education and model-making processes (Mweshi & Sakyi, 2020). A follow-up evaluation (post-test) is conducted after the intervention period to determine if there have been any changes in the participants' understanding, skills, and perspectives. This is significant in this study because the goal is to examine the effects of applying immersive technology on participants before and after its use.

3.19 Psychometric Questionnaire

There were no adverse reactions from participants who were assessed properly using a psychometric questionnaire about the perceived enjoyment of the game. All the quantitative data response is presented in a tabular form after collation, and with the assistance of academic specialists, all the data were evaluated with the test-post-test method. Finally, reliability assessments were carried out to determine and interpret valid and dependable results. Cronbach's Alpha for internal consistency was obtained, and it was equal to 0.76.

3.20 Parameters

Using inverse parameters in the dynamic evaluation of effects of immersive technology on design education and the model-making process is important. Among these parameters, 'Engaging Learnability,' "Cognitive Load," "Perceived Use," and "Perceived Acceptance" are particularly effective. The extent to which these technologies support instructional processes to help learners acquire skills and knowledge can be assessed by a factor known as "engaging learnability." It measures how well immersive technologies boost learners' motivation and interest by opening up and stimulating challenging subjects. The amount of mental effort students need to understand information presented through various devices is described by a concept called cognitive load (Mayer et al., 2002). Developed immersive technology and its integration into the educational process are effective in reducing cognitive load. According to Mayer (2024), research over more than four decades has shown that the cognitive theory of multimedia learning explains how people learn through words and visuals, highlighting three key principles: dual channels (verbal and visual), limited capacity, and active processing for meaningful learning.

The perceived use of immersive technologies in the context of 3D model making within design education is based on the technology's significant impact on students' learning achievements. When assessing the growth and influence of immersive tools on education, consider visual factors such as accessibility and ease of use, the educational and critical value of the immersive tool, and its coherence with existing learning resources. 'Perceived Acceptance' is a key characteristic of these tools that determines their sustainability in educational settings, encompassing components like technical aspects, regional or social factors, and modes of instruction. The application of the technology suggests that if the educational tools are effective, they can be utilised to address issues encountered in design education. It helps analyse students' perspectives on design education and the 3D model-making process using immersive technology (Razek et al., 2018). This level is known as perceived acceptance, representing students' readiness to adopt such devices as a permanent part of their education process. 'Perceived Acceptance' relates to a student's willingness to use these immersive technologies, influenced by factors such as educational value and improved comprehension.

3.21 Methodology used in Study-1: A conceptual study on the Feasibility of the application of Immersive Media for 3D model making

A brainstorming approach was used to enhance the immersive media learning experience in the model-making course. Brainstorming is a collaborative problem-solving method where group members freely suggest ideas without immediate criticism. This spontaneous idea generation fosters creative solutions to complex research issues. By documenting brainstorming sessions in research, readers gain insight into how collective input shapes the development of research questions, methodologies, or interpretations. Thus, brainstorming not only promotes diverse perspectives but also improves the overall quality and innovation of the research through the collective contribution of ideas from all participants. Two male designers with over ten years of creative experience developed mind mapping as an activity. Graphical representations are created based on various parameters and their effective combinations in virtual media. Strategies related to basic principles were devised concerning mind mapping before addressing the characteristics of VR and AR. In the Industrial Design Department at X Institute of Design, the hydrocarbons who specialise in building the model, especially in a number of sequential phases, are quite numerous. Learning theories have influenced the development of instructional tactics. A variety of VR and AR ideas with different functions and designs have been conceived. To evaluate the system's usability, five design experts, three males and two females aged 35 to 50 years, with an average of 10 years of design experience, were involved. Concerning the study, some specific ideas have been compared and discussed.

In this context of using immersive media, designing the interfaces may require significant effort; therefore, identifying the requirements first becomes even more crucial. Due to its 3D, engaging, immersive nature, virtual reality users can experience 360° views and perform full physical movements. The heuristic evaluation of the listed points was carried out (as shown in Table 3.1).

Table 3.1 Features for expert evaluation on the basis of (Sutcliffe, Gault, & Shin, 2005)

Feature	Description
Relevance to Context	Visualisations of AR and VR components should always be relevant to the real world and the activities for which the AR and VR representations are intended.
Alternative Learning Perspective	Provide a conceptual framework for the use of immersive media in model-making classes, especially in enhancing understanding and creativity.
Aesthetics of the Interface	Use amenable structures of existing metaphors in order to determine the geometry of the virtual elements by their function, affordances, and capabilities.
Visual feedback	Maintain equal integration of the extended or virtual experience by respecting the conventions of the platform and the practical design relevance to create a consistent experience.
Learnability	Eliminate cognitive overload that is not required to foster seamless interaction by avoiding scattered design, excessive distractions, and motions, so that users remain on task.
Task Accuracy and Usability	Bring cognitive congruence of the design to the users to make particular tasks effortlessly executable in an accurate manner, thereby increasing efficiency and user experience.

Sutcliffe, Gault, and Shin (2005) explored heuristic evaluation in virtual reality. They adapted existing usability principles to examine presence, recall, and interaction. The study employed case studies where multiple evaluators applied a customised set of heuristics to identify design problems affecting user immersion and information retention. By expanding on established usability heuristics, the research carefully assesses interfaces designed to investigate experiential aspects of presence, memory, and interaction. Flatken et al. (2024) investigated immersive and interactive 3D visualisation of large-scale geoscientific data using VR technology. The paper proposed a framework that supports scalable visualisations across devices by considering experiential aspects of presence, memory, and interaction. Heuristic evaluation could assess usability, immersion, and performance for effective data analysis across different devices. Furthermore, Crowe et al. (2024) reviewed virtual therapist interactions in immersive virtual environments for motor rehabilitation. The study highlighted improved patient outcomes, engagement, and personalised therapy potential. Further research is needed to optimise virtual therapist design for clinical use.

3.22 Methodology used in Study-2: User Experience Evaluation of a Virtual Reality Tool Used for 3D

3.22.1 Participants

Students studying industrial design across various disciplines, aged 18 to 23, formed the target audience. One of the requirements for this study was that participants be familiar with any kind of traditional 3D modelling programme. Each of them had used 3D software for at least a year. Thirty-four design students took part in a 15-day workshop on VR-based modelling software to create the VR tool user group. The participants were divided into two groups: Group A used traditional 3D modelling tools. This group consisted of design students who had previous experience with standard 3D modelling programmes like Blender, Autodesk, 3D Max, Fusion, and others (see Figure 3.3). Group B used Meta Quest 2 to try and build the same model after learning about VR tools. To enhance the prototype's presentation and fully engage the learner with the interface, the experimental group utilised virtual reality headsets (Meta Quest 2). Refer to Figure 3.4.

In Lombardi & Rizzi (2024), archaeology is integrated with other disciplines in a singular workflow where Blender is applied as a main open-source 3D modelling tool, creating 3D semantic virtual reconstructions that stem from

Figure 3.3 Students creating a task using conventional 3D software. (Image source: Author, 2023)

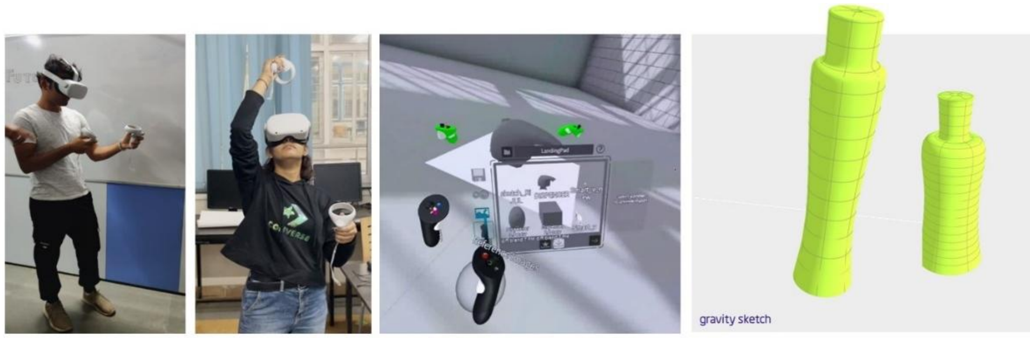


Figure 3.4 Students trying to create a water bottle using VR Meta Quest 2.
(Image source: Author, 2023, IMD Lab)

archaeological data. With Blender, one is able to create virtual reconstructions as well as 3D models of archaeological sites. Blender applies archaeological data within the Building Information Modelling integrated workflows.

Gong & Yang (2023) reviewed a method of 3D modelling using VR technology, focusing on cultural creativity products, including enhancement techniques that improve precision in 3D modelling and user engagement across systems and interfaces. Although it specifically discusses the work in terms of CAD and VR, principles of 3D modelling applicable to software like 3ds Max are central to the study. Generative AI is a relatively recent development that has gained traction as a tool for producing 3D models. This is in addition to its application in 3D modelling software. Musiol (2024) provides a detailed explanation of generative AI along with its differences from AI. It describes the role of reinforcement learning, generative AI's ability to create, transform, and enrich data, and its influence on the creative, gaming, and healthcare sectors.

3.23 Comparison of VR-Based and Conventional 3D Software for Design Manipulation

The study explored a menu bar-accessed collaborative virtual reality 3D application with sketch tools and other features. Figure 2B displays the user interface of the VR-based 3D tool. Collaboration enables teachers and students to communicate simultaneously, and a flowchart outlines the steps involved. Students begin by visiting the website's homepage, creating an account, or logging in with their ID. After logging in, students can upload .obj 3D models or photographs to build a virtual environment. Faculty members can then be invited to join the VR session after importing the same 3D items from the landing page.

The .obj file and sketch of the 3D model created by students in 3D software can be imported into a virtual reality space. The faculty can use the pen tool in virtual reality to mark overlays and edit models. Virtually rotating and moving the model allows them to assess its shape and identify which sides, curves, and features need adjustment. This helps students understand corrections immediately. Additionally, other users can integrate various 3D model files, such as Blender, CAD, Rhino, etc., within this VR application to create a multi-user collaborative space for collective discussion and editing. Through the creation, modification, and analysis of designs using computers, computer-aided design (CAD) enhances precision in engineering, architecture, and manufacturing. It facilitates data integration and rapid prototyping. "A Hands-On Introduction to SOLIDWORKS 2024" by Kirstie Plantenberg is an accessible book for learning 3D parametric modelling (Plantenberg, 2024).

Part prints and assembly drawings are designed for design and engineering students. Tools allow teachers to quickly observe and correct student mistakes. Both can sketch and manipulate objects, scaling them to real-life size, i.e., 1:1. Limiting interaction with rendering can negatively affect students' learning progress and create communication gaps. Students' learning abilities can be evaluated based on factors such as their capacity to visualise models, proficiency in geometric analysis, accuracy, and familiarity with dimensions. (Refer to Figure 3.5)

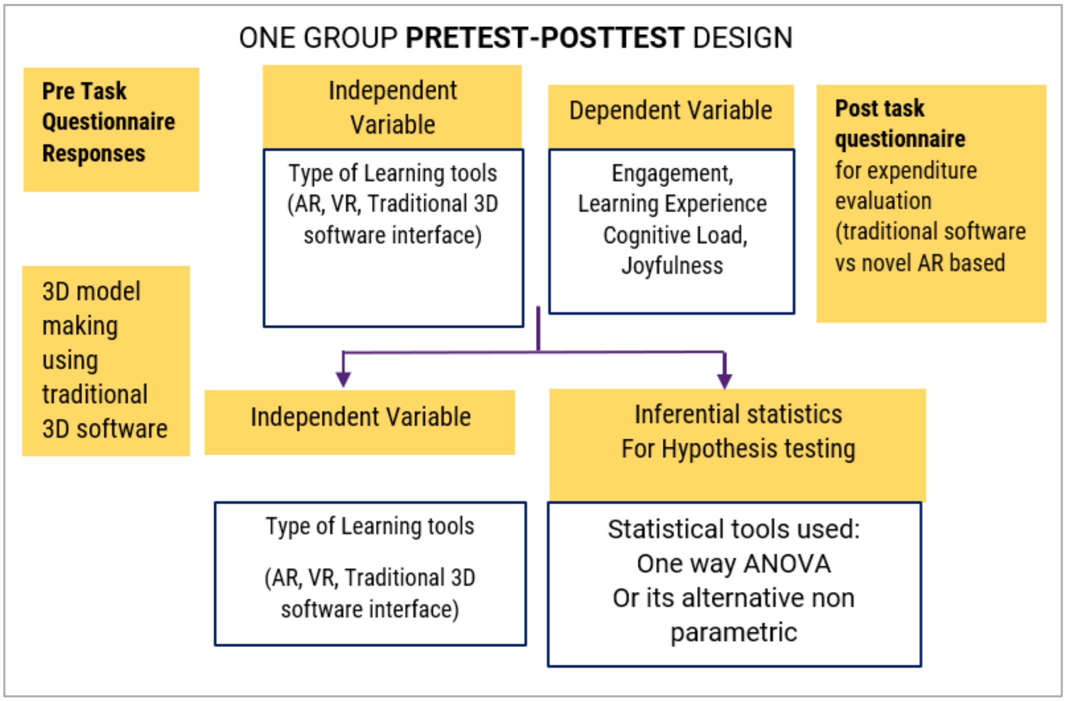


Figure 3.5 One Group Pretest and Posttest experimental design
(source: Author's creation)

Three-dimensional formats improve understanding of scale and proportion. VR lessons provide students with formats that enhance their grasp of these concepts. They offer sufficient visual cues for students to learn and self-correct. According to a literature review by Mohammad and Pedersen (2022), several factors influence the effectiveness of earlier heuristic evaluation methods. Elements such as embodiment, empathy, ease of use, immersion, and presence are vital for a positive user experience in virtual reality learning.

3.24 Research Framework

A between-subjects study design was used in this research. Two groups of industrial design students created identical models of a water bottle (see Figure 3.3) using either 3D software or VR software. Before the trial, students attended a 15-day VR workshop, which included exposure to the Meta Quest2 headset. During this training, they explored the collaborative features of the VR software. Both groups were tasked with designing 3D models of water bottles. Figure 3.4 shows the Meta Quest 2 virtual reality headset used in this study. The usability of the VR-based 3D tool was assessed through the random assignment of participants.

A pre-test questionnaire was given to collect information on the students' gender, 3D software proficiency level, and demographic details. During controlled testing, participants created a 3D model of a bottle. After completing this task, a post-task questionnaire was administered to assess the usefulness, perceived engagement, enjoyment, and overall acceptability of VR-based 3D model-making software compared to traditional software. Additionally, a separate experiment was conducted in the same setting to evaluate cognitive effort.

The NASA-TLX questionnaire was used to measure the cognitive load experienced while using both VR-based and traditional 3D software during the bottle modelling task (Hart, 1986). The NASA-TLX (NASA Task Load Index) is an assessment tool developed in the 1980s by the Human Performance Group at NASA's Ames Research Center. It is designed to easily and accurately measure perceived workload across multiple dimensions. The evaluation is tailored for aviation and human-machine systems, incorporating six key subscales: mental and physical demands, temporal demands, performance, effort, and frustration. The NASA tool is popular among PhD students and academic researchers due to its effectiveness in measuring cognition and perception workload during experiments. It is regarded as an essential instrument in psychology, human-computer interaction, education, health, medicine, and engineering. It allows for workload measurement in various settings, whether in laboratories or in the field, making it versatile across different contexts. This flexibility, coupled with its comprehensive and systematic approach to capturing multidimensional workload, explains why NASA-TLX remains widely used for measuring human performance and cognitive load (Bolton et al., 2020).

Cognitive workload assessment in immersive media like Virtual Reality (VR) and Augmented Reality (AR) is essential because these environments often impose complex sensory, movement, and time-related demands on users, which can influence performance and user experience.

Table 3.2 Mapping NASA-TLX dimensions in the context of Immersive media.

VR/AR Parameter / Clue	NASA-TLX Dimension	Cognitive Workload on the User
Navigation complexity & spatial demands	Mental Demand	Higher cognitive processing for wayfinding; AR adds dual-world attention load.
Physical movement & interaction	Physical Demand	Increased effort, fatigue, and discomfort from hardware use and gestures.
Time pressure in tasks	Temporal Demand	Faster decisions under pressure rais cognitive load.
Navigation success & task completion	Performance	Clear cues boost performance; confusing paths reduce it.
Managing virtual + real inputs	Effort	More work to interpret cues and operate controls; higher in AR.
Movement-related discomfort or system issues	Frustration Level	Excessive movement, fatigue, and technical glitches raise irritation.
Presence & immersion	Mental Demand, Effort, Frustration	Deeper immersion improves engagement but can increase load and discomfort.

workload refers to the amount of mental activity and cognitive resources that users need to utilise in order to engage with information and activities in these environments (Vidal-Balea et al., 2024).

3.25 Measures

Usability, engagement, enjoyment, and cognitive load were rigorously assessed using psychometric instruments. The Chowdhury A. usability scale from 2019 was effectively utilised for analysis in the research. The pleasure and involvement scales were sourced from work done by Thomas, Tuteja, and Chowdhury in 2021. The NASA-TLX questionnaire was used for measuring cognitive workload.

3.26 Statistical tools used in this experiment

Software called SPSS 20.0 was used to conduct statistical analysis, following Field (2024). The study employed the Mann-Whitney U-test to evaluate the significance of differences in 3D model production acceptability, engagement, enjoyment, and usefulness when comparing traditional tools to virtual reality tools (McKnight & Najab, 2010). Additionally, an independent samples t-test was used to identify significant variations in cognitive burden.

The third research study thoroughly examined the impact of Augmented Reality (AR) technology on industrial design students' understanding of 3D model creation. It established a clear link between students' engagement in industrial design using AR applications for 3D modelling and their previous experiences with immersive media technology. The study also investigated whether cognitive workload influences learner engagement when creating 3D models with an AR application. Additionally, it aimed to identify the factors that encourage learners' active involvement in 3D visualisation and model making. A comparison between traditional 3D software and augmented reality tools for model creation was conducted.

The Hypothetico-deductive method is used in research. This approach, as the core of a researcher's methodology, involves formulating a hypothesis based on theory or observation, deriving testable predictions, and conducting experiments to test the hypothesis. Zahran (2024) discussed the hypothetico-deductive approach as equally important in social psychology. The author described the process as making observations, forming testable hypotheses, deducing predictions from them, and empirically testing these to support or disprove the hypothesis. Geradts and Franke (2023) focused on implementing the hypothetico-deductive method in AI for Forensic Sciences, emphasising its central role in forensic work: hypothesis formation from observation, testing through predictions, and validation via AI analysis.

For the research, a cohort of industrial design students from fields such as product, transportation, retail, immersive design, and interior furniture design, among others, was included as participants. Non-probability sampling was used in the initial study (Kothari et al., 2004). All participants had at least one year of experience with 3D software. A one-week workshop focused on AR-based software was conducted with selected design students to create a user group for the AR tool. Participants in Group A used traditional 3D software, including Fusion, Autodesk, 3ds Max, and Blender. To assess various aspects of the user experience, psychometric scales were employed to measure engagement, ease of use, enjoyment, and cognitive workload. Our usability scale is based on Chowdhury A. (2019), while the engagement and enjoyment scales were adapted from the work of Thomas, Tuteja, and Chowdhury (Thomas et al., 2021). The NASA-TLX questionnaire was used to assess cognitive workload. The reliability of the questionnaire was rigorously evaluated using the extraction method, followed by a filtering process employing the Varimax rotation method and Kaiser normalisation. The study employed a dimension reduction technique. Certain parameters related to Perceived Ease of Use, Perceived Enjoyment, and Perceived Engagement displayed low item correlation coefficients and were subsequently removed. The parameter Perceived Acceptance, particularly the belief in the efficacy of using an AR-based system for 3D model creation, showed a notable inter-item correlation value of 0.757. As a result, variables related to Perceived Acceptance that received lower ratings were omitted. Values greater than 0.7 were considered for further analysis, leading to the use of a chi-square test to determine response variation.

3.27 Use of Augmented Reality integrating with AI

The comparative study of AR and traditional 3D software use led to further integration of artificial intelligence in the experimental design. This experiment extracted data from vertices and edges using a 3D visualisation map. Correlating this data helped identify vertices belonging to the same plane within the 3D Spatial System. The AR app scanned the design student's drawing or image idea to initiate the experimental design. AR visualisation of the 3D model tracks sketch selection. The rotating option progresses if the result is favourable. The design concludes if all sides are deemed suitable after rotation. Additionally, another design is suggested if the first is unsuitable. The experimental design involved group planning and AI (Sadiku et al., 2020). Maps for orthographic viewing utilise vertical and edge data extraction. A set of vertices that unquestionably belong to a 3D spatial single-plane system can be identified with the aid of the vertices and their correlation. The study highlights the versatility of AR in 3D visualisation.

3.28 Study of AR Vs VR comparison

Later, a comparative analysis of AR and VR for 3D visualisation and model building was carried out. To draw conclusions, the same Hypothetico-Deductive method was employed, and an experimental design was developed. The study investigated whether industrial design students using augmented reality (AR) apps for 3D model creation experienced higher levels of perceived engagement, ease of use, enjoyment, and lower cognitive workload compared to those using virtual reality (VR) apps. The difference between AR and VR, particularly in terms of their virtuality, influences human judgment based on how these technologies are presented and their alignment with the ecological context (Mills & Brown, 2021). Iterative insights and examples analysed by architects through real presence and separate examinations can be expedited by the organisation of computer-generated reality. According to the understanding, AR only assists in creating a partially computerised world, whereas VR constructs a fully virtual environment by immersing users in their senses continuously. Furthermore, AR superimposes 3D images, enabling communication between the virtual and real worlds (Checa et al, 2021).

3.29 Key take-away

This chapter offers a detailed overview of the experimental procedures, including research methods and the study design, and introduces the reader to the context of using the hypothetico-deductive approach in media-based exposure within design education. These methods and methodologies could be relevant for similar future studies and are particularly suitable for immersive media and design education. In the following chapters, the entire experiments will be presented along with results and discussions based on the aforementioned methods.

4 Chapter 4. Developing concepts in AR and VR for 3D model making and validation

Chapter Summary: During the COVID-19 pandemic, problems that had never been seen before caused schools all over the world to stop with uncertainty. To keep the school year going, most schools have switched to online learning tools. Design schools in India have begun offering lessons online through various platforms. Increasingly, immersive media such as Virtual Reality (VR) and Augmented Reality (AR) are being utilised to teach design. Many researchers have suggested that VR and AR can help students achieve specific learning objectives and enhance their conceptual understanding. This study identified the most common problems students faced while taking online classes, particularly in the model-making course. The discussion is focused on setting up VR and AR-based lessons that enable teachers and students to collaborate on discussions remotely. Using interactive media, the brainstorming process was used to come up with ways to make the dexterity skill-based model-making course better for learning. Heuristic research has established the effectiveness of augmented reality (AR) and virtual reality (VR) learning interfaces. The results clearly demonstrate that AR-based instructions, which are engaging and immersive, outperform those derived from VR. This study could be expanded to involve more design students to further evaluate the effectiveness of visual aids in an immersive media-based model-making class.

Keywords - AR, Immersive Media, Immersive Technology, Industrial Design, Instructional strategy, VR

4.1 Pandemic and Design Education

4.1.1 Background

Throughout the turbulent years of the COVID-19 pandemic in 2020 and 2021, people around the world found themselves navigating through a haze of uncertainty (Jena, 2020). This period challenged us all to adapt and rethink our daily lives like never before. Because of the pandemic, schools worldwide were closed, and the school timetable was altered. To keep up with academic work, most schools switched to online learning platforms. Design schools in India also began offering lessons online. Design education, however, is mainly hands-on and requires students to have access to workshops, tools, and often, ongoing one-on-one communication with teachers. Due to the pandemic lockdown, these rules were made stricter. In industrial design, students not only learned how to design things, but also how to create them physically. It became clear that the only way to teach classes with students was online.

Students actively participate in model making as they explore the complexities of design while developing skills to use various tools. They grasp basic concepts of form, shape, and space, which help them bring their imaginative ideas to life through models. Through this process, students gain a deeper understanding of how these elements work together to realise their ideas. When students create models, it's very important that they understand how to measure accurately and how different materials feel. They use more than one sense to help learn and improve their fine motor skills. For example, a course in model making that requires developing dexterity skills can be very challenging to teach and learn online.

People who study education technology are always seeking better ways to use media for teaching. Immersive Media appears to be one of these. Augmented reality (AR) and virtual reality (VR) can help students improve their performance in school and better grasp specific course objectives. Virtual reality (VR) and augmented reality (AR) may be excellent methods for allowing design students to participate in their model-making classes.

4.2 Design Education in India

The evolution and growth of design education in India has been significant. India has become a welcoming and favourable environment for practising design. The expansion of the design industry has made design education a vital focus in the country. India's design education sector is expected to thrive soon due to the country's demographics, increasing awareness of the importance of education, and people's openness to trying new things.

National Institute of Design, established in 1961, first design institution in India, serving as a landmark in the country’s creative history. It was established based on the India Design Study conducted by the renowned design duo, Ray and Charles Eames (Eames & Eames, 1958). People's thoughts and actions may be traced back to Rabindranath Tagore, but the attitude and method were shaped by India's war for freedom. They did not use the term "designer," yet Shantiniketan's endeavour to restore rural communities is one of the most significant design stories in history (Balaram, 2005). Because regulations and markets have evolved naturally, design education has become a magnet for those seeking to enter the sector. For design education to be effective, students must work on real-world projects and establish explicit linkages with their environment.

Design Pedagogy is a hands-on process. To learn design, you need to know about the different ways, processes, and materials used in design. As you move up the steps, the process stays the same, but the medium and methods may change slightly.

4.3 Learning Methods in Education

For the most part, humans use their senses to process knowledge and learn. There are three main ways that senses can be used: visually, audibly, and physically. One sense is more likely to be used by most students than others. Descriptive theories

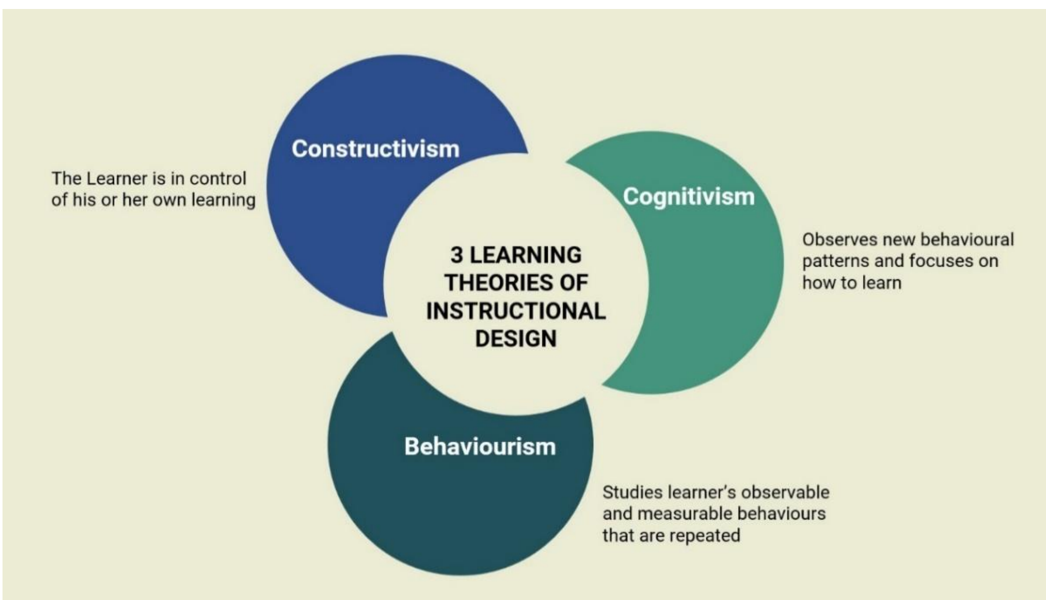


Figure 4.1 A theoretical framework integrating Kolb's learning cycle adapted from Carver et al.'s (2007).

of learning and prescriptive teaching are two main types of theories used in the Planning of schools. Though descriptive theories talk about how things are learned, prescriptive theories (Miller & Beebe-Center, 1956) suggest ways to learn them.

According to Ertmer and Newby (Miller & Beebe-Center, 1956), learning theory may be classified into three types: constructivism, cognitivism, and behaviourism. Experiential learning is a major constructivist activity that helps to establish learning outcomes. Kopanov emphasises that experiential learning (see Figure 4.1) is a dynamic process through which individuals gain understanding and knowledge through experiences and apply it in practice. Schema development plays a crucial role in helping students master various skills. A schema is a cognitive framework that organises information based on how it will be used. Since design education is inherently hands-on and experiential, Kolb's learning cycle theory can be effectively applied. Abri et al. (2024) conducted research on the application of constructive pedagogy to enhance student engagement in higher education. Constructivist pedagogy strongly highlights the importance of learners constructing understanding from their experiences instead of through rote memorisation. Constructivist pedagogy firmly establishes that effective learning arises from meaningful social interactions and personal interpretations. Teachers enabled learning by creating conditions that integrated inquiry, collaboration, and problem-solving. To deepen understanding, learners assimilated new knowledge during the active and authentic experiences.

Immersive Media in Education

Recently, there has been a focus on immersive media in design education. Consequently, the current understanding defines immersive media as the integration of technical equipment or processes with the real world through simulation methods. Today, it is commonly known as immersion, enabled by modern technology. Immersive media includes the impactful realms of VR, AR, and Mixed Reality (MR). Virtual Reality (VR) is described as an advanced system that combines software and hardware to transport users into a fully immersive digital environment, according to Kolb, Boyatzis, and Mainemelis (2014). Biocca and Delaney (1995) highlight three key features that make VR technologies transformative: immersion, presence, and interactivity. These features aim to enhance the user experience and alter their engagement with digital content. Di Natale et al. (2024) conducted a study on developments in immersive virtual reality and its clinical applications, emphasising VR's growing role in therapy, rehabilitation, and medical education. Technological advancements have improved the immersive quality of virtual reality, boosting clinical efficiency and patient outcomes. The review also notes areas needing further research, underscoring how VR could revolutionise medical practice.

In contrast, Augmented Reality allows users to integrate and interact with digitally created graphical overlays into real-world events, including audio and spatial sensory modalities. This project intends to put instructional techniques into practice by developing course objectives for online industrial design programs that leverage immersive technologies, such as practical model-making courses.

4.5 Methodology

To generate ideas on how the integration of immersive media into the model-making course will enhance learning, the brainstorming process has been employed. Innovative ideas for the integration of immersive media into the model-making course have been generated through the brainstorming process, significantly enhancing the learning experience. Two male designers with over ten years of design experience undertook mapping the concept.

A diagram is shown that helps readers understand the different aspects and their cohesiveness pertaining to the virtual media. The fundamental concepts have been effectively constructed using the mind mapping method, which aligns well with the attributes of VR and AR. Additionally, the essential steps involved in model-making have been thoroughly understood through insights gained from the Department of Industrial Design at the 'X' Institute of Design. Considering learning theories, instructional strategies were designed. Different AR concepts, together with different VR concepts and their intended functionalities, were detailed and created. Five experts (three males and two females aged 35-50) in Design with an average of ten years of experience conducted the usability evaluation. There have been some comparisons and discussions of the various concepts in the study. Complexities can be quite a prevalent aspect of the media interfaces for immersion; however, it makes it easier to determine what is essential. In fully immersive 3D virtual environments, depending on the particular experience, users can see 360

Table 4.1 List of heuristics adopted from (Sutcliffe, Gault, & Shin, 2005) for expert evaluation.

No.	Heuristics	Definition
1	Uniqueness of the Concept	Features that are highly unique in nature. VR and AR experiences should employ visuals and metaphors that make sense within the physical and task environments in which they are delivered.
2	Functionality	Give students a novel learning experience using immersive media in the context of a model-making course. Form conveys function. A virtual element's shape should be based on existing metaphors that the user is familiar with in order to communicate affordances and capabilities.
3	Aesthetics of the Interface	Synergy in visual appearance. There should be consistency in the virtual/augmented experience by adhering to platform norms from physical experiences.
4	Visual feedback	Easy to navigate, Designs should strive to reduce inadvertent distraction caused by designs that are too crowded, hectic, and/or movement-filled.
5	Learnability	It is simple to do the assignment with accuracy. Fits the user's perceptual ability.

degrees and experience complete physical motion. Evaluation has been conducted with respect to the following factors, as shown in Table 4.1.

4.6 Results and Discussions

4.6.1 Strategies for AR and VR Based Instructions

Instructional Strategies for AR and VR. There is a need for a conceptual framework that enables the design of a technologically dependent learning environment aimed at engaging all users. Both Chen and Teh’s (Chen & Teh, 2013; Walsh & Pawlowski, 2002) investigations highlight constructivist learning activities in VR and AR applications. Albarracin-Acero et al. (2024) explored the use of virtual reality (VR) video games for teaching direct current electrical circuits at a Colombian public university. Using a mixed-method approach, the authors conducted an action research cycle where they designed, implemented, and evaluated a VR teaching tool with the specific aim of enhancing undergraduate educational experiences. This tool was created to improve the learning experience of undergraduates. The study aimed to compare the effectiveness of a VR-based instructional method with a conventional approach on students' learning (Albarracin-Acero et al., 2024). Findings supported the effectiveness of VR in boosting instructional engagement as well as understanding of more complex STEM concepts. Faresta et al. (2024) reviewed recent literature on the application of virtual reality (VR) technology in education over the past five years. Immersive and interactive VR environments are shown to significantly improve critical thinking, problem-solving, active engagement, and collaboration, especially in STEM and professional education.

VR technology encourages deep learning more than traditional methods in the classroom by supporting the achievement of advanced cognitive outcomes, including teaching spatial reasoning and making appropriate decisions. Traditional methods of instruction still remain more effective than enduring challenges to widespread adoption, such as cost, infrastructure, teacher training, privacy, and inclusivity ethics. The Dick and Carey models suggest specifying the educational objectives and goals of training, analysis of inputs and outputs, learning processes, objectives and indicators of performance, types of tests (criterion-referenced), strategy, training/summative evaluation (Dick, Carey, & Carey, 2001). In spite of the different instructional design models that exist today, Branch and Kopcha (2014) state that all models encompass five pivotal activities: analysis, design, development, implementation, and evaluation. Shuell (1986) and Skinner (1989) emphasised the significance of broadly applicable learning theories in creating learning applications that utilise immersive technology. In these applications, learners receive rewards or penalties based on their responses, helping them grasp the effects of their behavioural patterns. This concept is relevant for systems that facilitate learning through responses that yield satisfying or displeasing consequences. As a result, students achieve specific outcomes and learn to adapt these lessons to their own experiences.

Since the experience is central to profound media, a convergent approach to the incorporation of immersive technology would be aligned with Kolb's learning cycle (Konak et al., 2014). The span of development of these learning theories extends to the depths of students' minds. Teaching materials on the Internet include notes, pictures, and written steps and photographs, which are probably shown on a monitor. However, the students are disadvantaged in this area since traditional teaching tools, such as 2D handouts, do not allow for much leeway in terms of viewing angles. It could be, for example, evaluation features like model impact, shape and dimensions analysis and understanding and judging complexity. The concept of proportions and scale can be imagined in detail by using Immersive media. Instructions that employ AR/VR will allow the students to have enough Visual clues to learn and self-correct if necessary.

4.6.2 Strategy Concepts for VR

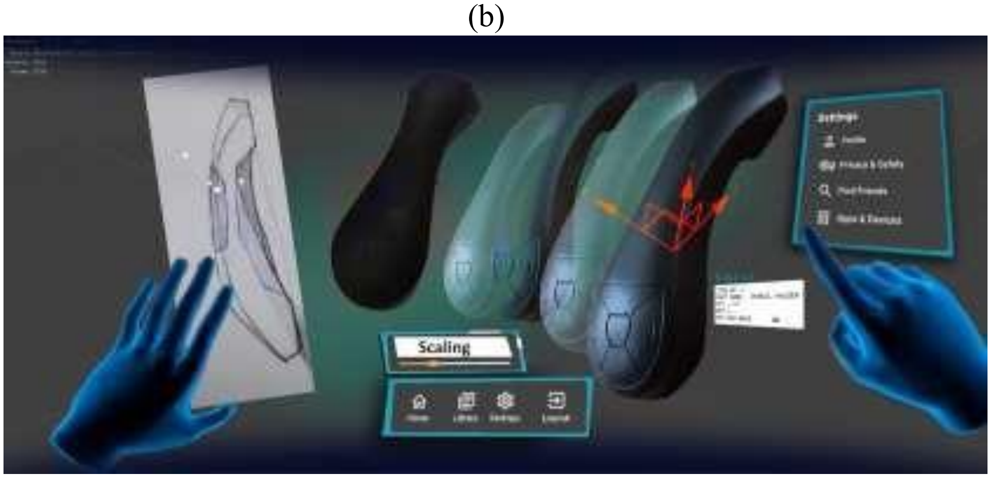
Students enrolled in the course on model making must first outline their design concepts and determine the final form of their models. The next step involves rendering these sketches into CAD/Autodesk models. For the construction process, materials such as MDF (Medium Density Fiberboard), thermocol, and POP (plaster of Paris) will be used to build the models.

Typically, students receive verbal instructions from the faculty. Through this guidance, they learn the process and collaborate effectively with their instructors. They also review the final models together. However, learning about the model-making process online can be quite challenging. Incorporating VR and AR technologies could greatly assist students by providing feedback and enabling more effective assessments during both the soft and hard launch phases.

The students and the faculty using the VR setup would be able to interact for the purpose of feedback sessions. That's why the students and the faculty using the VR setup would be able to interact for the purpose of feedback sessions. which must be comprehended in a virtual learning environment using videoconferencing.

(a)

(b)



(c)

Figure 4.2 VR based – Instructions concept (a) comparison of the sketches with the virtual model; (b) Interactions will be aided by VR features such as the Overlay method and rotation, different textures could be tried on; (c) Scaling of the virtual model to feel the actual size. (Image Screenshots source: Author 2021, IMD Lab)

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In designing a CAD/Autodesk model, dimensions are crucial; thus, students need to leverage the VR setup to measure dimensions in the sketch drawing with the virtual model. A three-dimensional image may be spun and examined from every angle. Overlay mode greatly enhances the understanding of volumetric deviations in the virtual model. This enables students to analyse the model more effectively and make necessary improvements to the physical model, ensuring it is built to a 1:1 scale with precise proportions. In a VR educational environment, students can view the virtual model from all angles and rotate it freely. Models can also provide additional knowledge just by clicking on the nodes. Popping the panels can make use of ray-casting. The textures on the model can also be altered and experimented with. A clear understanding of scale and proportions can be effectively achieved in a virtual setup. Sometimes, students struggle to grasp the concept of a 1:1 scale. However, with a virtual reality setup in place, they will have the opportunity to experience the completed model in an abstract way.

4.6.3 Strategy Concepts for AR

AR can be utilised to further explore the stages of model making, guiding students from the CAD model to the physical model. While working on their projects, students can use AR to integrate the physical model with the virtual CAD or Autodesk model displayed on their mobile or tablet devices. Object Recognition can be used in AR to locate the borders of the constructed model to align them with the virtual one. AR features assist in merging models and present a three-dimensional colour code as a means of indicating what should be corrected, 'Red' being used when nothing corresponds correctly, and 'Green' when the correct detail is found. The direct visual feedback enhances the enjoyment of interactivity. Allows for the improvement and correction of the model.

It will also provide further recommendations on how the respective adjustment can be made. The assessment of object recognition seems to widen the frontiers and reduce the effort of learning. As seen in Figure 4.3, the use of AR

(a)

(b)

(c)

Figure 4.3 AR based – Instructions Concept (a) The edges of the physically created model can be detected and matched to the virtual model in the AR setup. (b) An overlaid model would give volumetric comparison (c) It also enables to simulation of the mode the model to be reviewed in a real-world scenario. (Image source: Author 2021, IMD Lab) would allow the model to be seen and studied in a real situation. This helps the learner comprehend the model's scale and examine how human factors will function in the specific intended context. This work will facilitate the contextual evaluation of the appearance of the model and its components in their actual proportion. MDF is one of the readily available materials for Design students to explore physical model making. In their book by Sapuan et al. (2022) explored the industrial applications of nanocellulose and its nanocomposites, focusing on their use in manufacturing, including medium-density fibreboard (MDF).

4.7 Heuristics for the Developing Instructional Strategies for AR/VR

Heuristics based on instructional immersive media improve students' learning outcomes. Furthermore, when compared to a static interface, the results of AR/VR concepts show that student engagement is higher and more beneficial to both faculties and students. Immersive media allows for the reintegration of effective instructional strategies into online contexts, which should be evaluated in traditional educational settings. Immersive media allows for remote communication and simultaneous or asynchronous engagement.

4.8 Heuristics for the Developing Instructional Strategies for AR/VR

Immersive learning allows students to influence their educational experiences by connecting them to real-world situations. Additionally, immersive media supports analysis and encourages self-directed learning, not only in education but also in various fields, including raising social awareness. For a sensitive topic like menstruation, immersive media can address the issue maturely (Banerjee et al., 2021), offering visual cues for self-education to adolescent females from rural backgrounds.

Immersive learning enables students to shape their educational outcomes by connecting them to actual experiences. Immersive media aids analysis and fosters self-directed learning not only in education but also in a variety of other applications, including raising social consciousness. A sensitive issue like as menstruation may be addressed maturely via immersive media (Banerjee et al., 2021), providing visual clues for self-education to adolescent females from rural backgrounds.

4.9 Results of Heuristics Assessment

Metrics such as dimensional accuracy, joinery vertices, plane angles, and alignment checks are critical when evaluating a model. Regardless of the outcome, five experts with over ten years of design experience each were brought in to assess and ensure the effectiveness of the training materials and proposed interface by conducting a heuristic study. The results from the heuristics evaluation reveal the overwhelming impact the AR-based idea had on the overall learning experience. It also performed exceptionally high in novelty and utility of the concept, interface design, visual feedback, overall learnability, and effectiveness. Table 4.2 provides a summary of a heuristic analysis of VR and AR-based instructional concepts, adapted from Sutcliffe and Gault (2005). Experts gave AR-based instructional medium a mean score of 4.18, which is higher than the VR-based instructional

Table 4.2 Comparative Heuristic study of VR and AR strategy Based Concept Interactions.

Criteria	VR based Instruction Concept	Remarks	AR based Instruction Concept	Remarks
Uniqueness of the concept	2.80	Context is new	4.20	An effective way to communicate
Functionality	3.00	Remote learning	4.40	beyond geographical boundaries
Aesthetics of interface	2.60	Navigation interfaces	3.30	synergy
Visual Feedback	3.80	Able to view in 1:1 scale	4.60	Scaling and viewing in the real-life context
Learnability	3.40	Comparable understanding	4.40	Faster understanding
Total Average	3.12		4.18	

interface (mean score = 3.12), indicating that AR is better suited for a model creating course. The findings indicate that the AR-based idea excelled during the learning experience in terms of concept novelty, utility, interface aesthetics, visual feedback, and learnability. The conclusions were drawn since the VR-based training approach did not perform as well in the learning experience due to limited visual feedback.

4.10 Key Take-away

Augmented Reality (AR) training strategies are better suited for the ease of learning required in model creation courses. AR allows students to identify errors in physical models easily. Additionally, overlaying a CAD model onto a physical object is straightforward with AR. Research indicates that AR-based recommendations offer a more valuable learning experience than Virtual Reality (VR) approaches because they are often more cost-effective and readily accessible. AR creates a contextual understanding of how well a physical model will fit into its environment. It helps students connect their ideas to the real world and refine them without wasting materials. This can contribute to making industrial design education more environmentally friendly and sustainable over time. The concept of cohesive immersed instruction extends the dimension of feedback beyond physical borders. Students from almost any corner of the world can now interact not only with each other but with teachers and the instructional faculty from various geographical locations. To increase the effectiveness of student attention, it is recommended to integrate voice user interfaces (Ramadas & Chowdhury, 2020) with AR user interfaces.

The limitations of the research pointed out by other authors are particularly interesting. The impact of the VR/AR experience also depends on the speed of the internet where the faculty and the student are located, which could pose a challenge to the student-teacher interaction during the classes conducted over the internet. In immersive media, a faster connection is also necessary to allow for full real-time interaction. Moreover, in case of a slow Internet connection, the time it takes to superimpose a virtual model and compare it to an actual object can be quite long. This research has minimal user testing using a real prototype and a design learner. As a result, the efficiency of AR-based instructions for learning model creation may be investigated with industrial design students in the near future.

5 Chapter 5. Use of VR in 3D model making and its effectiveness

Chapter Summary: Faculties are currently interacting and conducting classes with students while using virtual reality (VR) tools. Educational practices today also encompass interactions in virtual settings and practical sessions aided by online tools. Only a limited number of studies have effectively explored how virtual reality (VR) technologies can enhance design education. The main objective of this study was to evaluate how industrial design students utilise virtual reality technologies in their learning activities. Additionally, it aimed to assess the effectiveness of these technologies in product design processes, specifically regarding the 3D representation of products. In order to investigate the cognitive workload, engagement and the general enjoyment of participants during the task, a sample consisting of two groups of 3D subjects tasked with the same work but presented with two setups: regular 3D application software and VR based application software was used. Statistical analysis indicated that compared 3D with VR and Non-VR exposure, the NASA-TLX score was higher in Non-VR exposure. Conversely, the average scores of engagements, enjoyment and usability captured were all higher.

Keywords: 3D model; experience; interactive media; industrial design; visualisation; virtual reality

5.1 Design Education and the Pandemic

Because of COVID-19 outbreak, people all over the world are using the internet for learning. Because of the plague, schools around the world have had to close, and classes have been moved around. Most schools have switched to online learning tools so they can continue their education (Jena, 2020). Students have had to deal with a lot of unknowns and problems as they have learned different courses and skills. To teach design, most courses are built on skills and practice. This meant that design education suffered significantly during the pandemic. Design Faculties, those who were having knowledge-based and lecture-based courses were able to offer their classes online, whereas design educators faced greater difficulties in teaching studio-based courses online (Ulferts, 2021). India's design schools also offer lessons online as part of their regular schedule. But because design education is based on hands-on learning, students and teachers often have to talk to each other one-on-one and use classes and tools. At the same time, the rapid evolution of technology encourages both students and teachers of design to consider providing such classes online. (Dhawan, 2020).

Most students in a course on model-making would have to understand the form, shape and space before they can make a model. It is pertinent for design students also to learn the theory and practice of making 3D models using some hand tools. Learners need to know about the materials, dimensions, and tactile traits (such as texture) in order to build a physical model. They might have trouble, though, getting the three-dimensional visualisation when they use 3D software to make their ideas digitally real.

Learning new concepts online can sometimes be challenging. Because of this, researchers in educational technology are continually looking for better ways for students in remote schools to communicate effectively. Immersive media, such as virtual reality (VR), shows promise as a viable solution. VR is an efficient and innovative approach to enhancing the learning experience. For model-making classes, the learning process through Virtual Reality would be more engaging for industrial design students (Kamin'ska et al., 2022).

The number of people who agree with online schooling has grown since the onset of the COVID-19 pandemic. Immersive technologies like VR and AR are becoming more common, and people are learning more about how they can be used. A lot of schools think that a mix of different ways of teaching is better for the students. Online platforms will still be used to teach and guide people after the pandemic is over. The other approach is hybrid, blended and online (HBO) learning, which is appropriate when learners are not confined to the classroom and are able to leverage HBO in order to learn a multitude of things (Singh, Steele & Singh, 2021).

5.2 Hybrid, blended learning in design education

The HBO education approach can help Indian design schools overcome challenges like insufficient teacher availability, lack of proper tools, and reliance on outdated lesson plans. Design schools can give students a more complete and varied education by using technology to personalise and adapt their learning, including projects that are important to the industry, and working with partners around the world.

In India, it is hard to find and hire teachers who have experience teaching design. In fact, there are way too few teachers and too many students (fewer teachers, more students). It has been reported by the All-India Council for Technical Education (AICTE) that the ideal teacher-to-student ratio in a design school is 1:10. However, there are more students than teachers at many design universities in India. At some schools, the number is as high as 1:20 or higher (Handbook, AICTE, 2023). This is a big reason why the HBO way of teaching is being used more and more in design schools. This emphasises the significance of AR / VR technology in design education in India. IIT, Guwahati, developed the Virtual labs to educate and interact with students through web app-based ecosystems. Virtual design workshops were also introduced (Dutta & Bhattacharjee, 2019). The students can even go to the virtual studio and learn how to do 3D, even at times when they are sick or miss the empirical training session. Design students will select their different design classes according to their choices and use virtual tools to learn new things to broaden their knowledge and skills.

The person using virtual reality feels like they are really in the setting when they are fully involved in it. VR interface is an innovative technology which allows a person to communicate with the computer within the boundaries of virtual space and its content. Subjects who are participants in the research and at the same time look at the virtual images can freely walk in the images, rotate them, touch the images, and even interact with the images or alter them (Zheng & Chan, 2001).

With rapid economic and societal advancement, computers have become essential across daily life and industry, significantly enhancing convenience, productivity, and product quality. In industrial design, computer technologies—especially virtual reality—integrate IT and sensing tools to simulate operational environments, supporting better product development. VR reconstructs reality using different graphic methods (Pan, Cheok, Yang, Zhu & Shi, 2006) to make three-dimensional, interactive environments that feel like real life (Ma, & Chui, 2023). According to Wang et al. (2024), extensive datasets from virtual reality (VR) environments were examined to identify trends within virtual design work. Movements within the space, as well as object interactions, were found to be associated both qualitatively and temporally with the resultant design. The authors emphasised the capability of VR to offer insights into the design process as it unfolds, which can be very helpful for instructors and practitioners in capturing and guiding the learning journey (Wang et al., 2024). Active learning metrics in VR have been suggested for use in forming guided tutorials, providing active learner feedback, adaptive teaching, and design thinking. Further, Zhou et al. (2024) presented direct solid modelling in virtual reality for systems architecture. Their methodology improved design efficiency and collaboration through the use of real-time 3D modelling, intuitive gestures, and immersive virtual reality environments. The framework provided a new tool for systems engineering by enabling architects to design and improve complex systems, increasing accuracy and reducing iteration time.

Additionally, there may be times when it seems like the time allotted is not enough to learn the whole set of skills during face-to-face teaching. Because of this, some of the inputs might be put online so that students can view them at any time. Karen Swan said that discussions can help students get to know each other better and that there are many things that can make online discussions helpful. Some of these are teachers talking with students, how often students have to participate, and how long their answers have to be in conversations. It's clear that these issues need to be looked into further. Because discussions in online classes are so important, using qualitative analysis to look at the quality of the answers to these discussions can lead to useful and insightful results (Swan, 2001). Mathew and Pappachan (2024) conducted an analysis of how adaptive course designs influenced student satisfaction and perceptions of learning in online learning environments. They noted the significance of design elements and the quality of interaction. Instructors worked towards improving the effectiveness of online learning, especially as educational innovation began to take shape. Key aspects such as learning characteristics, readiness, environment, and e-learning modes—synchronous or asynchronous—were critical to learner efficacy. The research explored how these learning qualities affected satisfaction and effectiveness, particularly considering the moderating role of learning mode. (Mathew and Pappachan, 2024) Students might be given more time to improve their skills with face-to-face training. When you use project completion to combine skill-based and knowledge-based learning in the hybrid mode, you can really understand and learn a lot more. In the area of design, new immersive media and other media and technologies are becoming more popular. VR and AR, which are immersive media, are becoming more popular in schooling (Hamad & Jia, 2022).

Students of industrial design need to be able to visualise things in 3D during model-making classes. It might be possible to teach these skills with immersive media like virtual reality. Students can study some inputs at their own pace because they can be accessed online or through electronic media. More advanced information can be taught online, but the basic courses have to be taken in person. Some advanced study materials are available online, which has led to the growth of a mixed way of teaching design. It can act as a mediating environment that allows learners to query further content at any point in time. However, it is clear that while in-person teaching will probably continue to hold sway for a long time, that practice is one of the ways of working, and there should be more options to communicate for both extreme situations, like world calamity, as well as the normal situations that make effective teaching a challenge. Hybrid classes allow students with a range of special needs to partake more easily, communicate with students in far-off places, help students maintain contact during extended absences and provide both students and staff with new means of communication.

However, a study article said that in order to guide future growth, VR-based learning environments need a detailed theoretical framework. It's important not to forget about the psychological learning process and the key factors that affect how well people learn in a VR-based learning setting (Lee & Wong, 2008). The study done by Muzata et al. (2024) reviewed the transformation of engineering education via virtual reality. This review looks at how virtual reality affects hybrid engineering classes, focusing on how it increases student interest, helps them learn new skills, and creates realistic simulations. The results show that VR can combine theoretical and practical learning, creating interactive, scalable training environments in hybrid settings.

5.3 VR for Visualisation in 3D

While studying industrial design, students frequently work with complex 3D models, making it essential for them to visualise 3D objects effectively. This study aims to explore how VR technology influences how industrial design students envisage 3D concepts. Visualising in three dimensions is a mental activity that requires considerable practice to enhance. If the process isn't quick and enjoyable, students may struggle, especially if they wish to pursue further studies in design. Over time, these difficulties can worsen and become bigger obstacles, hindering their creativity. Therefore, early awareness of this issue is important for design students. Immersion, presence, and interaction are key features that distinguish VR technologies.

Design faculties are increasingly interested in exploring immersive virtual reality (VR) because it enables them to see and connect with design concepts in entirely new ways. Over recent years, cutting-edge visualisation tools like VR have gained popularity among educators as effective means to help students grasp complex ideas and learn about new subjects. In particular, VR applications emphasise sensory and kinetic aspects, which are key to creating immersive experiences. Virtual reality devices are now frequently used in practical lessons to support design students in overcoming challenges related to visualising prototypes and making better design decisions. The immersive nature of VR, which actively involves students in the learning process, makes the educational setting much more motivating (Radianti et al., 2020). Education researchers have extensively studied tools like VR that enhance student interest and retention of knowledge (Di Natale, Repetto, Riva & Villani, 2020). A recent study analysed the role of virtual reality technologies in educating younger girls on hygiene during menstrual periods, which was helpful in increasing awareness. (Banerjee et al., 2021). Stress-free artistic processes created using the virtual tool "Tilt brush," which allowed individuals control of their hand motion and produced the desirable effect of creating 3D paintings (Mills & Brown, 2022).

When AR and VR ideas were evaluated using heuristics, it was found that incorporating interactive media in the classroom can enhance student learning. Additionally, AR/VR concepts have been shown to engage students more effectively than a static interface, which benefits both students and teachers. Immersive media-based model-making classes may be easier to understand than traditional classroom lessons.

North and North's (2016) study demonstrated that individuals in virtual reality environments experience a sense of presence. Yıldırım et al. (2020) state that the personalised learning environment provided by virtual reality increased students' interest and motivation in the course. The findings showed that virtual reality settings boosted motivation, encouraged critical thinking, and reduced anxiety. Akman and Çakır (2020) reported that virtual reality environments enhanced student engagement. Moreover, this study suggests that such environments also improved students' learning and recall, confirmed their sense of presence, and supported the development of professional skills. Additionally, the impact of an educational virtual reality game on the mathematical abilities and engagement of primary school children has been examined (Chien, Hwang & Jong, 2020). To evaluate virtual reality's role in design education, Nielsen's heuristic evaluation principles can be utilised; key factors include those outlined by Nielsen

(1995) and further discussed by Sutcliffe, Gault, and Shin (2005). Furthermore, Palombi et al. (2023) investigated the relationship between presence and cognitive performance in VR. The study found that a stronger sense of presence significantly enhanced memory, attention, and problem-solving. The results indicated that presence indeed influences cognitive performance in immersive environments and that VR holds great promise for cognitive training and rehabilitation.

Usability: How easy is it to operate the VR system, and how well can children move around and interact within the virtual world? How effectively does virtual reality (VR) assist students in understanding complex 3D design concepts and visualising how their designs will appear once realised.

Feedback*:* Giving students real-time feedback on the choices they make about their designs so that they can quickly change and improve them.

Immersion is the level to which students feel immersed in the virtual world and how that affects their learning.

Collaboration: This means that students can work together online, sharing and reviewing each other's work.

Accessibility means how easy it is to access VR systems and whether students can use VR outside of school.

What are the costs associated with VR systems, including hardware and applications? What implications do these costs have for schools looking to teach virtual reality design concepts in the classroom?

This brings up the question: Are Indian students engaging with the immersive spaces designed for the purpose of learning design, as similar researchers have illustrated in other contexts and case studies? It sounds likely that if design instructors were teaching in an engaging, interactive environment that increased collaboration and intensity, and where online learning was integrated, then using virtual reality could be a great tool for enhancing learning. Students will also have the opportunity to learn at their own pace and in their preferred way.

5.4 Objective of the Study

This research focused on the effectiveness of immersive technology, specifically Virtual Reality (VR), in enhancing 3D visualisation within Industrial Design curricula. This focus led to an experiment that compared a 3D design VR tool to traditional 3D design software. The study utilised a mixed-methods approach to closely analyse the user experience as well as the qualitative and quantitative outcomes of performance. Ease of use, engagement, interest, and enjoyment were all measured. Additionally, cognitive workload was assessed using the NASA Task Load Index (NASA-TLX). The experiment involved a basic 3D visualisation project centred around a bottle, chosen for its simplicity, which allowed for better control over the context and the user experience in both VR and conventional 3D modelling environments.

5.5 Methods

5.5.1 People involved

The target group was industrial design students between the ages of 18 and 23 from a range of design fields. The demographic information about the subjects can be found in Table 5.1. The study used a total of 128 students as the sample size. Prior

Table 5.1 Information about the people who took part in the Experiment Research

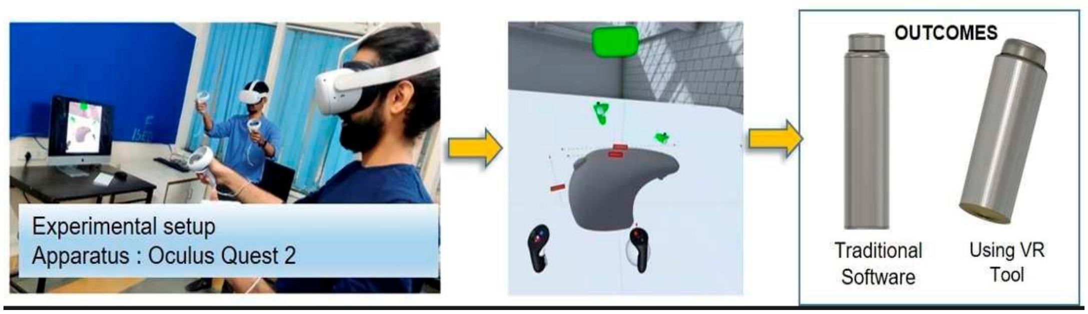
Parameter	Conventional 3D Software Group	VR-Based Software Group
	Usability. Engagement and Enjoyment study	
Mean Age (yrs)	20.62	20.53
Age Range(yrs)	19–23	18–23
Male: *n* (%)	15 (44.12)	15 (44.12)
Female: *n* (%)	19 (55.88)	19 (55.88)
n	34	34
	Cognitive Workload Study	
Mean Age (yrs)	20.21	20.21
Age Range (yrs)	18–21	18–21
Male: *n* (%)	5 (35.71)	5 (35.71)
Female: *n* (%)	9 (64.29)	9 (64.29)
n	14	13

to the study, students who had no knowledge of 3D modelling comprehension were removed; this was one of the determining factors for the final sample size. Every single one of them had used 3D tools for at least a year. For fifteen days, a class on

VR-based software was held with a group of 34 design students who used the VR tool. Two groups were made. People from Group A applied 3D design techniques

(A) (B) (C)

Figure 5.1 (A) A student making a water bottle using regular 3D software; (B, C) students trying to make a water bottle using VR Meta Quest 2. (Image source: Author 2023, IMD Lab)



(A) (B) (C)

Figure 5.2 (A) Student using the "Collab" feature of Meta Quest 2 to try out VR; (B) A student showing how the interface works in VR; and (C) models of water bottles. (Image & screenshots source: Author 2023, IMD Lab)

to the given three-dimensional tools. The participants were design students who were already skilled in using standard 3D applications such as Autodesk Fusion, 3ds Max, and Blender (see Figure 1A and video S1). Group B learned to use VR tools and attempted to create a similar model using the Meta Quest 2 (see Figure 5.1 B). Meanwhile, the experimental group used the Meta Quest 2 to enhance the presentation of their prototypes, allowing students to feel as though they were immersed in the interface. (see Figure 5.2 A). The study looked into what a collaborative VR app for 3D could do. The app has a menu bar where users can find sketch tools and other choices. Figure 5.2(B) shows how the suggested VR-based 3D tool would be used. The collaboration choice lets students and teachers talk to each other at the same time. A flowchart (see Figure 5.4) shows the steps that need to be taken to make this happen.

5.6 Design Manipulation Check (Traditional 3D Software vs. Software Based on VR)

Students first arrived at the home page of the given website and either registered for a new user account or signed in using their existing ID in order to begin the process. Once the students received access to the site, they could import the 3D models or pictures in OBJ format and perform a virtual room design, which they had done. Thereafter, the students can invite the other faculty members to the virtual room, and the landing page allows the authorised participants to include such models in the VR environment where the same 3D objects were used during the design.

5.7 Collab Choice

Students can import an image of a sketch drawing and the .obj file of the 3D model that they made in 3D software, together in a VR app for comparison. During the collaboration, educators can utilise the pen tool to inscribe their comments and

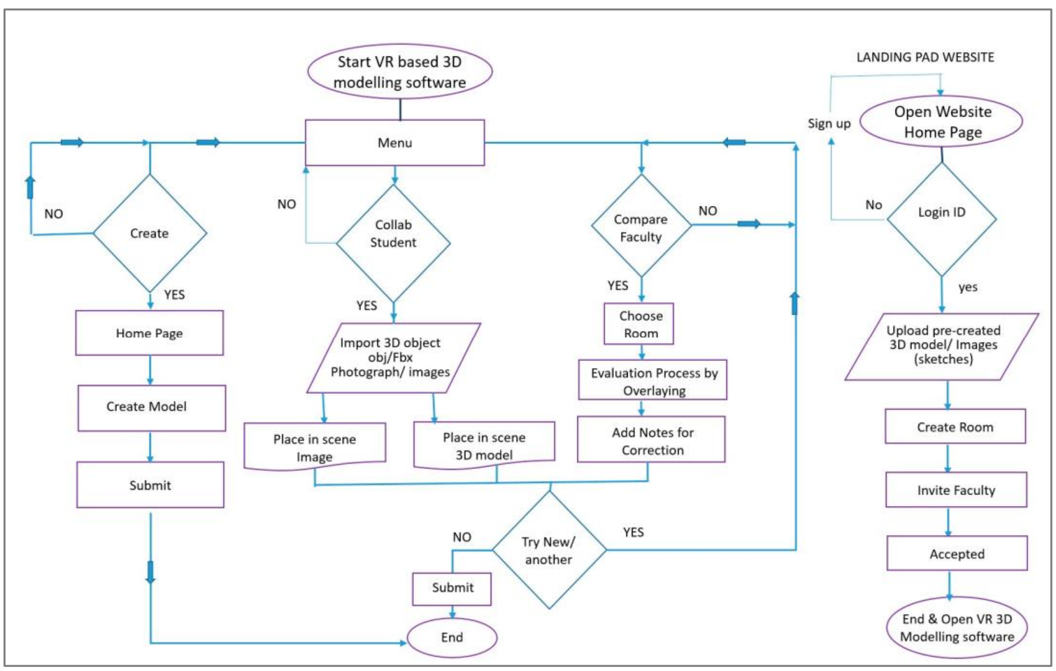


Figure 5.3 The flow chart of activity, which is followed while using the proposed VR tool, which enables students to interact and receive commentary from the faculty. (source: Author's creation)

modify parts of the models in the virtual environment. And when rotating and manipulating the model, they can inspect the differences that need to be made to the various sides and the curves. (Refer Figure 5.4) This will assist the student in immediately comprehending what imperfection requires correction and how to correct it. The 3D model can be overlaid on the real picture by the learner to view it in its actual proportions of 1:1. This VR solution is custom-built to allow importing of other 3D models from programs like Blender, CAD, Rhino, etc. Multiple users can also collaborate on similar files in the lobby and discuss the file. Now, the design faculty does not have to waste time dissecting the wrong assumptions, as the tools allow revision of the mistakes committed by the students. Students can reconstruct the object, rotate it, and adjust its dimensions to one and see its real-life 1:1 proportion. This is especially helpful when students can't meet in person, which can hinder their learning and make it harder for them to talk to each other.

To assess their level of learning, several criteria could be applied, for example, students' ability to perceive and mentally visualise the model, their ability to conduct geometric operations, precision and accuracy, and even their understanding of the size of things. 3D settings can help you understand scale and proportion better. The VR-based directions will give students enough visual cues to learn and make mistakes on their own.

A review of the studies has been conducted by Mohammad and Pedersen, who emphasise that several key factors influence the benefits obtained from heuristic evaluation methods that were popular in older studies. Tools, methods, program parameters and the personality of the evaluators are some of them. Some of these factors are the tools, techniques, and program settings used, as well as the experience and personality of the people doing the evaluation. The study's goal was to either evaluate a current VR app, develop a new one, or establish new guidelines. It was evident from the literature review that embodiment, empathy, flow, immersion, and presence are the five critical aspects that must be considered to enhance user enjoyment in VR learning environments. In the same way, the next comparison study (Mohammad & Pedersen, 2022) was carried out. Inferences that can be drawn from both regular software and VR-based software are shown in Table 5.2.

Table 5.2 Comparative study of the inferences of conventional and VR-based software.

Sl No.	Parameter	Conventional	VR-Based 3D Software	Inferences
1	Ease of use	There are concealed commands within menus and submenus.	It is easier to use because of hand gestures.	VR-based software is more convenient for 3D model making
2	Immersion	Negligible immersive quality (presence)	Users can seamlessly interact with the working 3D model (zoom, rotate, scale) view from different angles to get the feel of presence.	VR-based software is more immersive in creating 3D models
3	Accessibility	Voice commands are included	Voice commands and hand gestures are included	VR-based software has more accessibility for inclusive design
4	Interaction style	Input devices: using mouse and keyboard, touch-based interaction if a touch-based monitor used	Using hand gestures, VR hand controller and a wearable device (Microsoft MYO)	VR-based software is more intuitive to use
5	Visual appeal	Elaborated interface has been used	Visually delightful interface	Visually pleasant in terms of UI interfaces in Conventional 3D software as well as in VR-based software.
6	Precision	More precise 3D models could be created in Conventional 3D software.	Lack of precision in the 3D output models	Conventional 3D software can provide greater precision. However, VR-based software can achieve precision if the created model is exported in a compatible

				format and edited in conventional 3D software.
7	Online collaboration	Limited collaborative opportunities	All types of collaboration are possible.	The VR-based system allows for collaboration between users, allowing them to interact with the intended model simultaneously.
8	Error notification	Present	More lively and feedback notification	VR-based software has better error notifications
9	Natural interaction	Absent	Hand gestural interaction Voice-based interaction (VOI)	VR-based software has a very visceral way of using hand gestures
10	User control and freedom	Present	Present	Both are good in terms of user control freedom
11	Implementation of Muscle–Computer Interface (muCI)	Limited Possibilities	Enormous possibilities	In VR-based system Muscle–Muscle-Computer Interface (mulCI) can be incorporated.

5.8 Working Definitions

- How easy the software is to use is what "ease of use" means.
- Presence is the idea that you are really in a computer-made world or environment.
- Accessibility means being able to get the information you want regardless of your race, culture, gender, or language limitations.
- The way a person will use the system is called their interaction style.
- Visual appeal has to do with how nice the system looks.
- Precision is how well you can make 3D models that are the right size.

- Online collaboration is when more than one person uses 3D tools online to work together.
- Error Notification is a way to show error messages to cut down on mistakes made by people.
- What people do when they talk to each other is called "natural human interaction."
- Freedom and control for users include doing the same thing in different ways.
- Muscle Computer Interface, which focuses on the muscles and has dielectric properties, a muscle-computer interface (muCI) is able to capitalise on the muscles ‘electronic activity for communication with computers. Chowdhury, Ramadas & Karmakar, (2023) explain this.

5.9 Procedure

The investigation involved two samples of industrial design students (Figures 5A & 5B). They were asked to model a symmetrical bottle; however, one sample was asked to perform the task with a common 3D software (Figure 5C) and the other did the same 3D in virtual reality. Before taking part in the project, the students who used the VR tools were shown both 3D and ways to work together for 15 days. One group of students was asked to make a 3D model of a water bottle, as shown in Figure 5C. In this study, Meta Quest 2 was used as a VR tool, as shown in Figure 5A. The study subjects were randomly assigned to assess the effectiveness of the suggested VR-based 3D tool.

The student's background, such as the gender, demographics and the skills in 3D software, was provided through a pretest questionnaire. The controlled study space where the respondents performed the task was the 3D bottle-making task. When the task was finished, a post-task evaluation was used to find out how easy it was to use, how engaging, how fun, and how acceptable regular 3D software and VR based 3D software were to the subjects. The same study setup was previously described, but another experiment was performed to measure cognitive workload. Hart (1986) observed differences in mental workload during a 3D bottle model-making task when comparing conventional 3D software to VR-based 3D software.

To evaluate cognitive load, the NASA-TLX questionnaire was utilised. This tool was effective in assessing the participants' cognitive workload.

5.10 Measures

Psychometric scales were used to assess user satisfaction, interest, pleasure and even cognitive workload. The usability metric was developed from the work of Chowdhury (2019). The engagement and enjoyment measures were adapted from those of Thomas, Tuteja, and Chowdhury (2021). Feedback was obtained using the modified NASA-TLX survey in order to derive cognitive stress levels.

5.11 Stats Used in this Study

As noted by Field (2024), statistical analysis was conducted utilising SPSS version 20.0. The Mann–Whitney U-test was employed to assess whether there were significant differences between the regular groups and VR tools in terms of how easy they were to use, whether people enjoyed them, and how acceptable they were for making 3D models (McKnight & Najab, 2010). An independent sample t-test was also used to find changes in cognitive load that were statistically significant.

5.12 Results

The research explored the differences between traditional 3D software and VR-based 3D software. It looked into various factors like how engaged users felt, how much they enjoyed the experience, their willingness to accept these technologies, and the mental effort required to use them. Findings indicated that participants deemed traditional 3D software to be more user-friendly. Conversely, the VR-based software was rated higher in terms of engagement and demonstrated a significantly greater level of enjoyment, which suggests a preference for the immersive and enjoyable experience afforded by VR. Task completion times were notably shorter with the VR system, reflecting enhanced efficiency. Although the cognitive load associated with VR software was marginally elevated, this appeared to correlate with increased interest and active involvement. In summary, notwithstanding its initial lack of intuitiveness, VR-based software has exhibited considerable promise as an effective and well-accepted educational tool, offering additional advantages in collaborative and immersive learning contexts.

5.12.1 How Usable It Seems

The average score for how easy people thought regular 3D software was to use was 3.857, and the average score for VR-based software was 3.381. It follows that most respondents found very few individual views seeing the VR software as easy to use as fleshed out 3D software [Mann–Whitney U = 414.50, Z (67) = −2.040; $p = 0.04$]. This result can be expected because students in 3D conventional group were already exposed and so far, familiar to a great extent to what 3D conventional tools offer compared to the tools targeting virtual reality. Even though we gave you three free trials of VR tools, it would take some time to get used to the same one. The Kyaw and team's systematic review notes that among various forms of automated education, including online training, video lessons, and conventional approaches such as lectures, books, and 2D models, the application of VR in healthcare education is more effective in bridging the knowledge and skills gap. VR has the potential to change the way health professionals learn because it is new and flexible. Using VR technology may help people learn and improve their skills after a session (Kyaw et al., 2023).

5.13 Parameters

It was 3.881 for regular 3D software and 3.523 for VR-based software in terms of how engaged people thought they were with it. In terms of interest, there's very little difference between VR-based software and 3D software. [Mann–Whitney U = 561.50, Z (67) = −0.206; $p = 0.837$]. Since both forms have mean scores above 3.5 on a 5-point scale, they are both interesting. Figure 4 shows the results of a comparison test between conventional 3D software and VR-based software for usability, involvement, enjoyment, and acceptability.

Guan et al. (2021) suggested a VR-based pottery-making activity for a technology class that used interactive learning and useful VR tools. This made students more creative and interested in learning. This study added to what is known about how virtual reality can encourage creativity and participation among K–12 students. In 2018, researchers looked into how VR tools could be used instead of

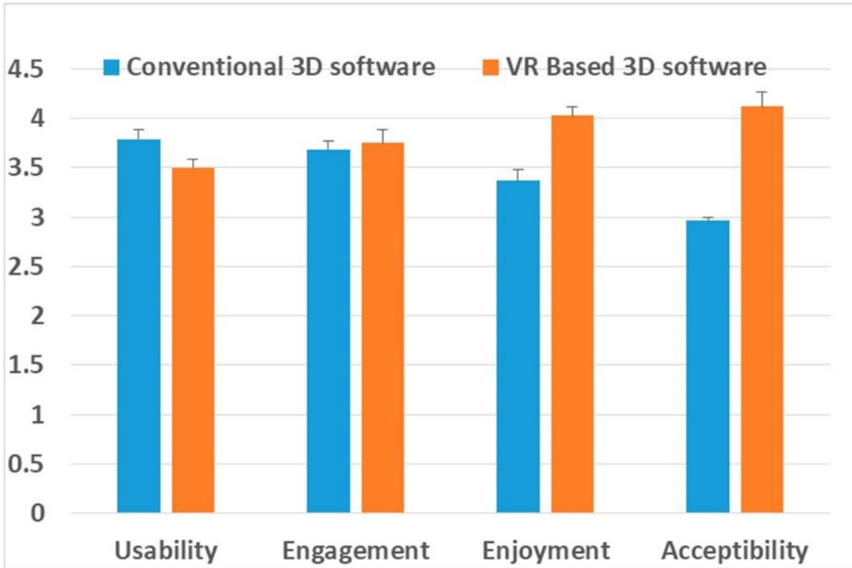


Figure 5.4 Displays the results, which demonstrate the extent of difference between a conventional 3D software and VR-based 3D software.

standard textbooks for learning. The data show that virtual reality (VR) could be a good alternative, as it has similar levels of performance, higher levels of engagement, and positive reception. The results indicate VR could be a good alternative for future studies as it has similar performance levels, reception and high user engagement. These effects can also be related to residual learning and impact the post-experience outcome (Allcoat & von Mühlenen, 2018). Recently, Makaransky and Mayer (2022) compared immersive virtual reality field trips to traditional teaching methods and found that VR produced learning outcomes that were on par with or better, significantly higher levels of engagement, and positive student feedback. Because VR can reinforce both immediate and delayed retention of material, its findings support VR as a viable alternative to traditional pedagogical approaches. (Refer to Figure 5.1)

5.14 Enjoyment

The average rating for VR-based software was 4.190, while the average rating for standard 3D software was 3.5. People's enjoyment of 3D software and the VR system differs significantly. [Mann–Whitney U = 246.00, Z (67) = −4.248; p =

0.000]. Because of this, students liked the VR-based method better than regular 3D tools. A recent study states that introducing gamification and quest-based techniques in a 3D social VR environment provides an exciting opportunity for people from different backgrounds and institutions to collaborate. This has the potential to enhance and differentiate conventional approaches to fostering open and distance learning in higher education institutions. Game-like features foster critical thinking and create a sense of interest, motivation, and autonomy in students, making them more willing to learn. Researchers have found that using virtual reality to engage students who are not interested in math in math activities can help them perform better academically. They also found out that when a faculty member uses virtual reality in the classroom, it is very beneficial since it makes a lesson more enjoyable, interesting, and fun for the learners (Akman & Çakır, 2020).

5.15 Consumed Time Factor

Students using the standard 3D application for this task completed it in an average time of 21.12 minutes; however, within VR-based applications, the time was much shorter, being 18.15 minutes [Mann–Whitney U = 538.00, Z (67) = −0.493); ($p < 0.001$)]. Furthermore, a great contrast was observed in the efficiency of making the 3D model between using regular software and using VR applications. Therefore, the VR-based approach works effectively.

5.16 Rating of Acceptance

In comparison with traditional 3D applications, the VR-based application received the highest score of 4.118 and was rated more positively by fewer people. The acceptance rates appeared to be quite different for VR-based software concerning the 3D application [Mann–Whitney U = 149.500, Z (67) = −5.840; ($p = 0.001$)]. It can therefore be concluded, as shown in Figure 5.5, that there are numerous advantages of using VR-based software over the ordinary 3D application.

In recent studies, the use of virtual reality apps in training and continuing education for nurses has been studied in more depth. Their study showed that how

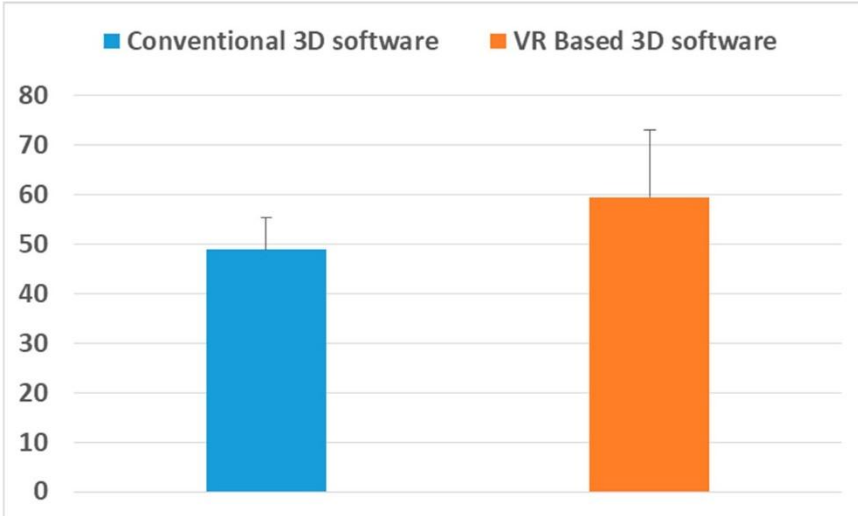


Figure 5.2 A comparison between the acceptance of both conventional 3D software and VR-based software.

much VR should be used in nursing education depends on how well each student accepts it (Lange et al., 2020). In the same way, this study found that most of the design students gave better scores on the acceptance scale. As a result, they are open to the idea of using VR technology to teach design. Because of this, the suggested VR-based 3D tool could be used to teach design.

5.17 NASA-TLX Study

From the statistical test, it seems that the type of software used has no significant effect on the tasks completed by the individual, whether it's the traditional software or the VR-enhanced software. t (25) was -1.3744 has a significant level of 0.18. Regular 3D software gets a weighted average rating of 48.885, which is slightly lower than the VR software average weighted rating of 59.453. That the brain load was higher says that a more interesting software was the VR-based one (Von Janczewski et al., 2022).

The result is that heuristics can tell us a lot about how virtual reality can be used in design education by checking how well and quickly this method helps students understand and picture complicated 3D design ideas. Because they applied the same cognitive and motor abilities, the students believed they performed as well as the control group, according to the NASA-TLX results (Devos, 2020). By the end of the test, the test group's students felt good about utilising VR apps to visualise objects in three dimensions. The students highlighted the VR tool was very useful and said it could change the way learning is usually done in schools.

5.18 General Discussions

According to the study, VR-based 3D software is more fun, captivating, and acceptable than using standard 3D software. Not many researchers have looked into how students could benefit from combining traditional lab work with virtual reality (VR) in engineering. They said that VR-based learning settings could be helpful for engineering students. In the same way, our study shows that VR-based 3D software will help students of industrial design and design education (Ren et al., 2015). Researchers investigated the possibility of using 3D and VR models in Civil Engineering lectures. They discovered an academic study that inspired the development of a video game that allows users to control the lighting in buildings. This model makes it easier to share data about the physical behaviour of parts over time in a way that is both visual and interactive. This means that if students use CAD and VR tools in the classroom, they might decide that these skills are important for their professional growth. The research further demonstrated that narrated prototypes can be created in a virtual setting (Sampaio, Ferreira, Rosário & Martins, 2010).

Natural interaction means the body and its movements are used effortlessly to alter views of 3D objects. As postulated by Zhang et al. (2020), even making contact with basic 3D tools can be enjoyable and, via this, assists individuals in the imagining process. The study found that people had a lot more fun with VR-based tools because the interface allowed for more natural and gesture-based interactions. Hand movements are a big part of 3D tools that work in VR. They make it easier for students to use the program naturally and can make the whole experience better for everyone. Choi et al. (2018) suggest that hand gestures are also beneficial in helping students construct 3D geometry mentally and aid in the perception of volume. The volume Motion and Perception, edited by Flash & Berthoz, (2021), compiles interdisciplinary research on how the brain interprets space and time

(Flash & Berthoz, 2021). In order to investigate motion and perception and provide insights into spatiotemporal dynamics, the book combines neuroscience, psychology, and artistic viewpoints. Similarly, the proceedings volume Neural Information Processing: 30th International Conference, ICONIP 2023, edited by Luo, B. et al., presents cutting-edge research in neural information processing (Luo, B. et al.,2023)

Any application program must be user-friendly, and the same goes for VR-based 3D tools. There is no need for learners to invest considerable time in exploring the software applications, as it is expected that they will be easy to use. Ali et al. (2022) investigated how the user interface affects satisfaction and perceived cognitive load in users while using VR and VR-based 3D tools. We found the opposite in our study, where the suggested VR-based 3D software scored much lower on the ease-of-use scale than regular 3D software. This could be because Indian industrial design students are unfamiliar with the VR-based tool, which led to this outcome.

Collaboration means that more than one person can work on the same 3D model at the same time. Collaboration can make the experience better for users by making it more social and dynamic. The enhancement of settings where two or more VR users can interact with one another, regardless of distance or location, was examined. The findings indicate that users who can see each other perform sense-making tasks well.

The enhancement of settings where two or more VR users can interact with one another, regardless of distance or location, was examined. The findings indicate that users who can see each other perform sense-making tasks well. The study gives us useful information for creating joint visualisations in a virtual reality setting. In VR-based 3D, working together made the experience better for users and facilitated their thinking. Collaboration has been improved in the study that used VR tools (Chen, 2021). With these tools, students should be able to work together and share their ideas with others in real time. Also, the traditional theory of cognitive workload says that if using gamified software brings about more cognitive load, the user may have a better experience and find the system acceptable (Guerra-Tamez, 2023; Wang, Thompson, Uz-Bilgin & Klopfer, 2021). Among the advantages reported was a reduction of cognitive load related to problem solving with low-fidelity design goals in the classroom, while concentration or the amount of media interaction with the relevant area was increased. Another advantage was that the authors were able to make learning easy, authentic and fun in the virtual environment. (Özgen, Afacan & Sürer, 2021).

The software that was VR-based for building 3D models is much superior as it has more varied features, making it easier, adding more depth, allowing for wider usage, making it simpler, and letting one interact with it much more naturally. And these factors made the VR-based 3D tools more attractive. This paper suggests that a greater degree of engagement is consistently associated with greater mental effort. Stated differently, the VR configuration is simply more engaging. We found out that the use of VR-based 3D tools has greater meaning and cognitive workload compared to traditional 3D tools. This means that they are better. According to a recent study, people who used the software thought it was easier to use when they could connect with it more physically. It's also possible to have better learning experiences with VR because it uses more than one sense (Muñoz, Barcelos & Chalegre, 2011). They looked into what makes it easy to use 3D in VR. For industrial design, it is important to look into how easy, accessible, and comfortable virtual reality 3D is to use. Good user design is very important for virtual reality to work as well and quickly as possible. The three most crucial criteria elements pertinent to the usability of 3D in the VR context are noted in the research as being engagement, dynamic compatibility and flow effects (Huang & Lee, 2022).

5.19 Key take-away

In the end, traditional 3D software programs and VR-based tools let you see 3D objects from various perspectives. Virtual reality-based 3D tools are easier to learn than traditional 3D software programs, even though the latter offer more features and functions. When it comes to accuracy, VR-based tools might not be as good as regular 3D software. Creating 3D models and visualisations using a VR-based 3D tool is easy and enjoyable. This would be very beneficial for artists and design specialists who need to rapidly create concepts and sample production. As virtual reality technology advances, it will be intriguing to observe its impact on 3D visual communication and determine which techniques will emerge as dominant. The aim of this research was to illustrate the effectiveness of immersive VR technology in the education of industrial design through practical scenarios and demonstrations. The study assessed the perspectives and sentiments of both students and educators regarding the implementation of VR technology in industrial design courses. It concluded that using VR in the classes could make the design process more like real life and simulate professional work. Based on these results, VR has a great chance to change the way industrial design projects are done.

Our results also show that immersive media could be used to help people learn how to make 3D products. 3D visualisation VR technology can provide advantages for design students in order to overcome the limitations related to the evaluation of prototypes and make appropriate design decisions beforehand without physically creating them. Students can determine the shape and form before creating the final solid model using virtual reality. This conserves the use of materials and promotes sustainable practices within the industry. Consequently, this approach seeks to ensure the future of industrial design education without compromising the well-being of the environment. Immersive media's collaborative features make it possible for students and teachers from all over the world to connect and give and receive feedback beyond physical limits.

This study investigates whether Indian students react in the same way as other studies have reported to immersive design environments for learning. Virtual reality (VR) is a powerful teaching tool for design students, as it offers a dynamic, interactive, and immersive learning environment suitable for hybrid education. Furthermore, it allows pupils to study when and how they choose. The concept of the research given here has never been used in design education, especially in India.

Due to the limited time frame of the study project, the cognitive workload was assessed with fewer students than normal. However, we got the right direction in the data based on what we know about cognitive workload theory. For students and design faculties, the hybrid online blended style of design education would open up more doors. With industrial design schools, the same study could be done in more depth. If the research were to be extended to all industrial design schools, the same study could be conducted using much depth. As other studies have indicated, students who remain long hours engaged in using VR-based 3-dimensional software may experience dizziness (Yu et al., 2019) and may also experience eye troubles (Aher et al., 2022). The issues related to human factors and VR sickness faced in the proposed 3D tool could be addressed in the near future.

6 Chapter 6. Application of AR for 3D modelling and comparative analysis

Chapter Summary: Recently, Augmented Reality (AR) has emerged as a groundbreaking technology in the education sector, offering immersive experiences that enhance learning through tools such as 3D visualisation. AR has potential in industrial design education for addressing difficulties in spatial comprehension. Traditional model-making methods often involve trial-and-error approaches and the use of clay. To create tangible products, design students start by drawing perspectives and orthographic sketches. While CAD software aids in visualising models, it presents steep learning curves. This paper examines how the AR interface enhances 3D visualisation in model-making. The case study explores how industrial design students engage with learning in augmented reality (AR) settings, employing a hypothetico-deductive approach to investigate this relationship.

The participants, comprising both undergraduate and postgraduate students, provided feedback through questionnaires built with a Likert scale (measuring perceived engagement, enjoyment, and acceptance) to produce numerical data for statistical analysis. Responses specific to each parameter were analysed using appropriate Chi-square tests. Design students ($p < 0.05$) in the study either agreed or strongly agreed that the proposed AR interface is engaging, enjoyable, and acceptable. The mean scores from the Likert scale (ranging from 1 to 5) for perceived learning engagement, perceived enjoyment, and perceived acceptance were 4.04, 4.16, and 4.76, respectively (all indicating agreement with scores above 3.5). The proposed AI-enabled AR interface is advantageous for design learners to visualise virtual product models through intuitive interfaces. Student sketches can be mapped from orthographic to 3D spatial forms using extracted vertices and edges, which accelerates 3D visualisation and streamlines decision-making.

Keywords: 3D Visualisation, AR interface, design acceptance, engagement, enjoyment,

6.1 AR Domain

6.1.1 Definition of AR and its application

In the digitalisation era, Augmented reality (AR) is an essential technology that supports model visualisation processes at a significant level. AR provides digital contexts like pictures, videos, and 3D models to represent physical worlds (Ulferts, 2021; Kee, Zhang, & King, 2023). Usually via smartphone, tablet, or an AR headset. While virtual reality immerses a person in a completely artificial world, this form of augmented reality adds digital layers to the real surroundings, making the physical environment richer and more interactive. In health care, marketing, entertainment, and education, AR is used extensively to improve functionality. This AR improves how items are seen and interconnected in design (Arce, Suárez-García, López-Vázquez, 2022). AR lets product designers visually prototype and test products, which is faster and cheaper than physical prototyping. Augmented Reality makes it easier for students to grasp complex topics by bringing them to life through immersive, hands-on experiences. AR creates more interplay between the digital and the physical worlds in order to enhance user experiences.

Through dynamics, AR improves physical component visualisation and engagement. According to Silva et al., AR displays virtual images of AR-enabled products on the screen, improving customer experiences and product representation (Silva, Fachada, De Andrade, & Códices, 2022). In business, AR is essential for 3D product visualisation, representing products to customers. This AR aids decision-making, provides virtual support, and effectively connects the real and virtual worlds.

6.2 AR for Industrial Design Learners

AR increases student engagement and replaces traditional learning with digital learning environments in industrial education. Today, educational digitalisation boosts AR adoption in industrial learning. AR provides immersive, direct experiences that enhance learning and retention outside of the classroom. AR helps visualise the physical component structure in this case. AR helps design the learning process for students by providing customised services, tracking progress, and understanding learning preferences. The individualised educational trajectory enhances student motivation, fosters creativity, and develops analytical reasoning and solution-focused approaches, all of which are crucial for achieving success in industrial design (Kaplan, 2021).

The AR supports collaboration and gives students virtual collaborative environments. AR eliminates the need for physical models, resources, and materials in design education (Sadiku, Musa, & Chukwu, 2022).

6.3 VR & AR concepts in 3D model making

The development processes of 3D models, both in the Virtual Reality (VR) realm and in the Augmented Reality (AR), have a focus on the visualisation principle. VR provides students with interactive methods for developing models to simulate a world for interacting with virtual objects, unlike AR (Banerjee et al., 2021). According to Eastman and Computing, students can experiment with design iterations, investigate spatial relationships, and learn proportions and scale through this interactive experience (Eastman & Computing, 2021). AR lets students see virtual models in real-world settings. AR develops design concepts and uses real-time feedback to add virtual features to real objects. Based on these concepts, earners rate their ideas' appeal and engagement.

During Industrial Design's 'model-making course,' learners need to grasp principles like form, shape, and space. They need expertise in using manual tools for making 3D models. Understanding tactile attributes and facing challenges in digital visualisation using 3D software is important.

The course begins with sketching concepts, creating CAD models, and physical materialisation. Faculty guides students in correcting forms and refining designs. Traditional teaching methods for 3D visualisation have limitations. User interfaces and experience design significantly influence student engagement. Learner motivation increases with intuitive AR interfaces and clear instructions. The quality and realism of AR visualisations are vital for learner immersion. Customisation and interactivity in AR are key to student engagement. Interactive lessons, gamification, and advice boost participation. A supportive learning environment encourages learners to master AR-based model creation. Such an environment, with clear instructional materials, opportunities for peer collaboration, and expert assistance, motivates learners to explore, experiment, and develop AR skills (Wohlin & Aurum, 2015). The availability of AR-enabled devices and institutional adoption of AR greatly affect learning, highlighting the importance of integrating AR into the curriculum for student growth. The 2024 study by Melnyk et al. investigates augmented reality (AR) to improve documentation and anchor inspection in conventional tunnelling. Published in Tunnelling and Underground Space Technology, it suggests an AR-based system to enhance real-time data capture, streamline reporting, and minimise errors in tunnel construction. The approach combines digital tools with on-site processes, demonstrating practical benefits for efficiency and accuracy in managing tunnelling projects (Melnyk et al, 2024). Dieck et al. (2021) edited the book, which examines new developments in virtual reality (VR) and augmented reality (AR) technologies. It covers theoretical underpinnings, creative applications, and real-world applications in a range of industries, such as business, tourism, and education (Dieck et al., 2021).

An analysis of the literature reveals several key findings. More specifically, there is little research focused on the use of innovative new technologies in Design Education. The use of immersive media and its potential impact in this area is largely ignored. Moreover, there is a significant gap in research literature on the use of AR and VR technologies for developing motor skills in design courses, highlighting a need for more research. Additionally, there is a need for exploration into the integration of AR/VR for visualising spatial dimensions within the educational context.

6.4 Aim and Objectives

This chapter delves into the role of augmented reality as an immersive medium, investigating its impact on the ability of industrial design students to visualise 3D models—especially during the model-making process. It looks at how this hands-on approach compares to acquiring similar skills through conventional 3D software.

The aim is to study the effectiveness of AR solutions using Immersive media, such as AR, in terms of Perceived Engagement.

- To study the effectiveness of using an AR-based solution in terms of perceived enjoyment in 3D visualisation in model making in comparison to the conventional method.
- To study the comparison of cognitive load reduction using AR versus the traditional method of model making.
- The study of the efficacy of AR in terms of Acceptance of the mode of teaching.
- The objective was also kept for perceived Ease of use in AR in 3D visualisation in model making

6.5 Methodology

Hypothetico-deductive was the research design utilised in the study. The hypothetico-deductive method was used as the research design. This approach usually involves generating hypotheses based on theory or observation, designing experiments or collecting data to test these hypotheses, and then accepting, rejecting, or modifying them according to the evidence gathered. A cohort of industrial design students from product, transportation, retail, immersive design, and interior furniture design, among others, was included as participants. This diversity suggests the research aimed for broad representation within the industrial design discipline. Purposive Sampling was done in the initial study (Kothari, 2004). The sample was 19–26 years old, Undergraduate and Postgraduate Design students, N=55, M=24, F=31, from Pune, India. Students without 3D software model-making or prototype creation knowledge are excluded. Each of them had at least a year of experience working with 3D software packages.

As part of the experimental design, an AR tool user group was formed after conducting a one-week workshop with some design students in order to investigate the specifics of AR-based software. The study divided participants into two groups. Group A consisted of design students already familiar with traditional 3D software. They worked with common industry tools, including Blender, Autodesk, 3ds Max, and Fusion. Group B, on the other hand, consisted of design students who utilised an augmented reality (AR) tool for their tasks. As for the rest of the experience, it was rational to assess the cognitive load along with perceived engagement, ease of use, and enjoyment using standardised psychometric measures. The usability scale was based on the work of Chowdhury, Thomas, Tuteja, and Chowdhury (2021) alongside the engagement and enjoyment scales. Cognitive load was assessed using the NASA-TLX cognitive task load questionnaire developed by Hart in 1986.

6.6 Measures

The reliability of the questionnaire was ensured through factor extraction with the data, which was then analysed using the Varimax rotation method with Kaiser normalisation. This was part of a larger method of dimension reduction employed in the study.

In this process, several items pertaining to Perceived Ease of Use, Perceived Enjoyment, and Perceived Engagement had low inter-item correlation scores. Those items were removed for more accurate results. Of the items in Perceived Ease of Use, the gesture control parameter had the strongest correlation with a score of 0.960. Within Perceived Enjoyment, the item "faster visualisation" scored the highest at 0.960, and other items with weaker correlational strength were purged. For Perceived Acceptance, the statement "using an AR-based system to create 3D models is a good idea" had a robust correlation of 0.757, which was high enough to justify removing items with weaker scores in that dimension.

Table 6.1 Comparison of NASA-TLX scores between the use of VR, the use of AR, and the conventional use of 3D software for the visualisation of 3D models.

Parameter	Using VR	Using AR	Using Conventional 3D Software
FRUSTRATION	2.07	0.80	5.30
PERFORMANCE	2.09	0.90	2.99
EFFORT	2.09	0.87	2.99
NASA_TLX_SCORE	3.67	2.06	4.00

In the NASA-TLX evaluation, participants gave a frustration value of 0.798, a performance value of 0.868, and an effort value of 0.869. Temporal demand was quite low and thus was excluded. The Cronbach's alpha value of over 0.7 for the questionnaire confirmed its reliability. When the NASA-TLX factors' wise scores were compared, marked differences were observed in the case of frustration, performance, and effort. Please refer to Table 6.1 for the detailed results of NASA-TLX differences.

In the statistical computations, both perceived ease of use and perceived enjoyment had a combined chi-square value of 21.356 with a single degree of freedom, whereas perceived acceptance produced 11.756 with one degree of freedom as well. All of the findings were significant at the .0001 level, confirming that all the measured scales were reliable.

6.7 Statistical Tools employed in the study

Data from the study were analysed using SPSS 20 Software, wherein the Chi-Square Test was employed in sampling. The Chi-square test assessed the significance of frequency distributions across different response categories and aided in testing the reliability of single-item psychometric measures measured on a 5-point Likert scale. Its unique purpose in data analysis is model enumeration. Dimensionality and value reduction were also done using the Rotation method. The further analysis obtains the value "more than 0.7" as a value. In terms of seminal works, the "Chi-Square Test" sample testing approach has a statistically significant probability of less than < 0.05 as regards the variance of a population (Longo et al., 2022). For this particular study, it would appear that AR-based tools are more effective for standard evaluation, whereby such evaluation is of a 3D model making prototype. This results in enhancement of engagement neuroscience load as evidenced in the study (data ">3.5" and "NASA-TLX" "<2.5"). In this study, a one-way Analysis of Variance (ANOVA) was employed to compare the means of two or more independent groups, with the objective of determining whether any statistically significant differences exist among them. In the study, NASA-TLX was used as a dependent variable for comparing the traditional method of using 3D software with the multiple group comparison using Augmented Reality as an independent variable.

For this project, a primary study was considered, for which questionnaire interviews were planned and designed according to the pretest-posttest design using a 5-point Likert scale. Further, the responses were collected in numeric data, which was used for further interpretation and analysis using arithmetic measures.

6.8 Experimental Design

The entire experimental design has been centered on augmented reality. The experiment has been conducted by extracting the vertices and their edges from the data according to the 3D visualised form. Linking this facilitated the obtaining of the vertex sets that the vertices tap into that the 3D Spatial System intended (Refer to Figure 6.1) for a single plane. This research started with the AR app because it has successfully scanned the drawing or the image idea constructed by the design student. The application of AR for 3D models' visualisation has been acknowledged for pinpointing the selection of the sketch. When the result is promising, then it goes through to the next phase, which is the rotation part. If, during the revolution, the design has been determined to be good for all sides, then it's over. From this time onward, if the design is not approved, they will be told of a different design.

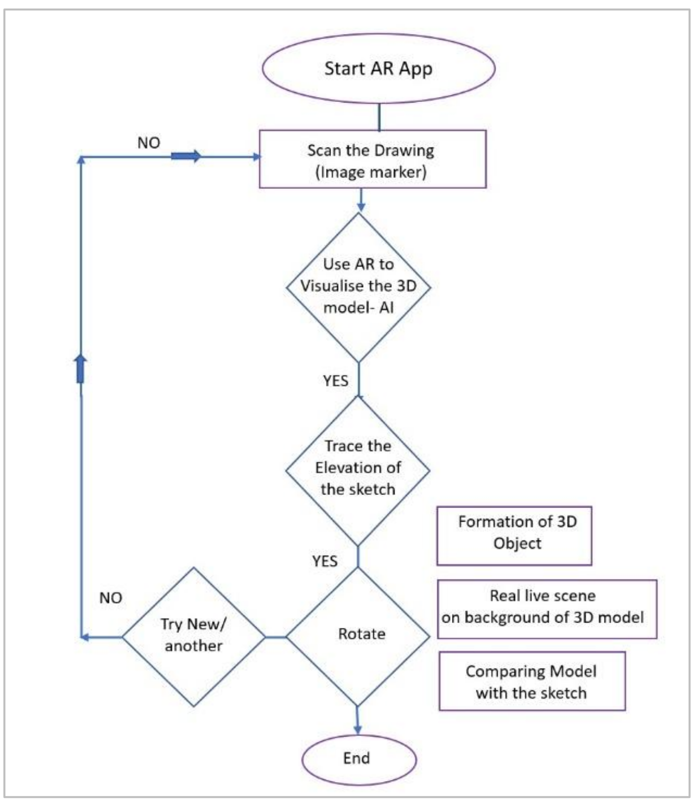


Figure 6.1 AR Flowchart (source: Author's creation)

The experimental design had its plans, and these were executed in designs whereby the incorporation of AI was accepted for this stage (Sadiku et al., 2020). The projection of the data for the vertical as well as the map has been projected and is deemed to be relevant to all other orthographic views. The correlation between the vertices and their respective angles helps to obtain a set of vertices which are essentially a part of a 3D spatial single planar system. The built-in support was provided by uniting the AR foundations and integrating AR visualisation.

The experimental design plans had groups, and in the course of this step, the application of AI, in conjunction with AR, was encouraged (Banerjee et al., 2021). It has been proposed that the extraction of data for the vertical and the edges

Figure 6.2 Experimental design- AR Design participants handling the proposed AR intervention. (Image source: Author 2024, IMD Lab)

used in the map in the orthographic view, compared to other maps. The vertices and their interactions assist in generating a set of vertices that most certainly constitutes a 3D spatial single system of planes. Connecting together the frameworks of AR produced a built-in support which allowed for the integration of the visualisation made on AR. Refer to Figure 6.2 to observe the different phases of the AR-based system.

6.9 Results

The comparative assessment of conventional 3D software versus Augmented Reality (AR) applications highlights clear differences in Perceived Engagement, Enjoyment, Acceptance, and Cognitive Load. AR applications excel in fostering engagement, as a large segment of students endorse AR for creating 3D prototypes, reflecting stronger participation than with traditional tools. Enjoyment is generally high for AR, yet most students display moderate approval rather than strong enthusiasm, signifying a positive, though not exuberant, experience. AR tools achieve higher perceived acceptance, with students expressing a distinct preference for their use in industrial 3D modelling settings. Importantly, AR imposes less cognitive demand, offering intuitive and accessible interfaces that contribute to a more enriching and effective learning environment. Collectively, AR is affirmed as the more engaging, enjoyable, accepted, and cognitively accessible solution.

6.10 Perceived Engagement

The results of the perceived engagement comparison between conventional 3D and AR have come out that the standard deviation for traditional 3D software is "0.47," with a mean of "3.52," "(Conventional Vs AR)" "[F (2,112) =9.499: *p*=0.0002]" are among the significant observations that were made during the learning engagement as a result of the 3D model variation for software production. The conclusion reached states, “(M_{AR}= 4.04, SD_{AR}= 0.21)” because the average perceived learning engagement is highest in the AR application (Eastman, Newstetter, & McCracken, 2021). What this shows is that the AR application is the best when it comes to Learning engagement in the case of the creation of 3D model prototypes for industries, students, or learners (Table 6.2). In fact, just 5% of the student population have held strong views regarding the engagement being perceived; the other 95% have endorsed the parameter.

Table 6.2 Comparison of Perceived Engagement of traditional 3D software and AR-based software.

Perceived Engagement			
MODE	**N (Count)**	**Mean**	**Std. Deviation**
Traditional 3D Software	34	3.52	0.47
AR	55	4.04	0.21

Similarly, research done by Thanya (2025) revealed unique preferences and issues pertaining to different technologies within the context of Engineering higher education. Students reported that AR technology was intuitive and minimally disruptive to their learning habits, with 78% of them favouring AR in group learning activities. While VR users reported having more vivid and impactful learning experiences, 23% of them mentioned some discomfort with prolonged use. Faculty comments suggested that AR was easier to implement because less training and technical support were needed, compared to VR. Also, the study published by Tene et al. (2024) described the effects of the implementation of immersive VR and AR. This paper explains some possible benefits of AR, including reduction of errors, better engagement, training uniformity, and greater engagement, promoting the contexts in which AR would outperform VR for medical education. Both AR and VR have the potential to be transformative, but the paper underscores the more practical advantages of AR in specific situations, such as cannulation training.

6.11 Perceived Enjoyment

The perceived enjoyment parameters were consistently high, with an N count of 55 for AR, with a mean of 4.16 and a standard deviation of 0.36. Nevertheless, the standard deviation of the conventional 3D software is 0.63. Variations in the development of 3D model software are shown in Table 6.3. Comparison of Perceived Enjoyment between traditional 3D software with AR-based UI have resulted in some substantial discrepancies in the enjoyment factor. The calculation was represented by the following result: "[F (2,112) = 21.387; p = 0.0001]". The average value has been determined to be higher than that of the "traditional 3D software" (M_{AR}= 4.16, SD_{AR}= 0.36) (Meža, Turk & Dolenc, 2015). This demonstrates that the AR application is the optimal choice for its intended purpose. Please refer Table 6.3. In summary, it is possible to conclude that only 16% of the students expressed a strong agreement with the aspect of Perceived Enjoyment, while the remaining students only agreed and did not express a strong opinion.

Table 6.3 Average Perceived Enjoyment among design students.

Perceived Enjoyment			
MODE	N (Count)	Mean	Std. Deviation
Traditional 3D Software	34	3.5	0.63
AR	55	4.16	0.36

6.12 Perceived Acceptance

There are significant differences in perceived acceptance, which are undoubtedly evident in students' acceptance due to the variance that occurred in the 3D software development paradigm. The average acceptance value has been the highest for the AR tool. In the case of AR application, it is the best application in terms of Acceptance for the 3D model among industrial-level students (Razek, Van Husen, Pallot, & Richir, 2018). The traditional 3D software has a standard deviation of ***"0.17"*** and that for the AR is ***"0.43"*** respectively, refer to Table 6.4. Thus, the standard deviation has been found to have a distinct gap. Out of all the students, 75% have a strong opinion about perceived Acceptance, and 25% of the students agreed with the parameters of perceived Acceptance.

Table 6.4 Average Perceived Acceptance among design students.

Perceived Acceptance			
MODE	N (Count)	Mean	Std. Deviation
Traditional 3D Software	34	2.94	0.17
AR	55	4.76	0.43

6.13 Cognitive Load

Studies show that AR-based solutions are more developed and perform better than traditional processes due to their accessibility, simplicity, and other features. Participants had lower cognitive demands when using the AR-based tool, indicating a more stimulating and engaging experience (Dorta, 2007). The findings support participants' positive views of the system's acceptance, simplicity, enjoyment, and engagement. AR reduces cognitive load and boosts engagement, improving 3D model creation learning. The mean rating of conventional 3D software was 48.885. The AR-based tool in this study achieved a higher result score than the conventional method, which is more convenient for the creation of 3D models in terms of ease of use, immersiveness, accessibility, intuitiveness, and natural interaction style. NASA Task Load Index (TLX) scores below 2.5 in AR-based systems suggest this tendency. Thus, the AR-based system is more effective than the traditional 3D software base as Figure 6.3 shows. the augmented reality (AR) integration's impacts on teaching within the context of blending the virtual and the real world for visualisation, interactions and engagement in the framework of an engineering pedagogy. Their study centered on the use of AR in education.

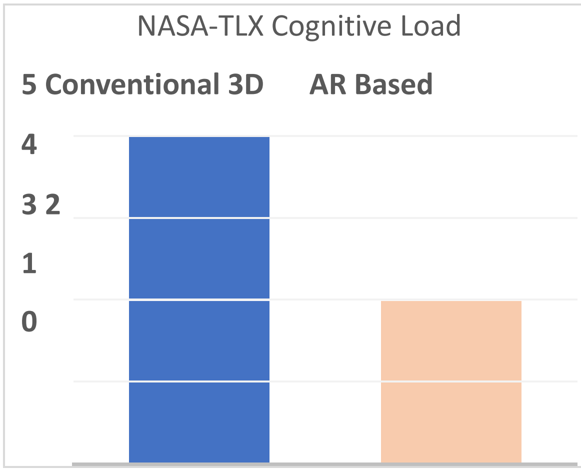


Figure 6.3. Cognition load NASA-TLX – Mean Variations (conventional vs. AR based interfaces).

6.14 Discussions

A comparative study between AR and traditional approaches was conducted to assess the effectiveness of AR in industrial learning and 3D model development. Cognitive load significantly influences AR's effectiveness compared to conventional methods. According to Sadiku, Musa, and Chukwu (2022), AR-based teaching is as effective as 3D methods, especially when those methods are too costly or hazardous. AR is more accepted in education than VR, which can diminish its effectiveness. Features such as acceptability and accessibility help AR technology drive innovation in industrial learning. As per Meza et al. (2015), AR is widely appreciated because it improves understanding and encourages the integration of project documentation. They illustrate how AR can be useful in civil engineering by overlaying digital models onto real environments, enhancing planning, design, construction decision-making, visualisation, and teamwork. In their review of augmented reality (AR) applications in civil infrastructure during the Fourth Industrial Revolution, Xu and Moreu (2021) underscore how AR can boost engagement and learning. AR facilitates immersive, interactive experiences that improve comprehension of complex infrastructure concepts. These studies collectively highlight AR's transformative role in civil engineering and architecture, simplifying workflows while deepening understanding of intricate spatial and structural concepts (Xu & Moreu, 2021). Industrial design students can benefit from using AR in 3D model creation over standard 3D software and virtual reality, according to Pribeanu et al. (2017). AR presents a similar cognitive load, along with higher acceptance and enjoyment, and increased engagement compared to traditional methods. This underscores the significance of AR technology in industrial learning and promotes student engagement through digitalisation. Regarding Virtual Reality, VR users frequently experience headaches and dizziness, which emphasises the importance of user comfort and safety (Moro, Štromberga, Raikos, & Stirling, 2017). Consequently, AR is considered the most effective application in terms of perceived engagement, enjoyment, and acceptance for 3D model creation among Indian industrial design learners.

6.15 Conclusions and Future Scope

The study focuses on developing a low-fidelity AR-based mapping solution that has some limitations. The main challenge was the learning curve associated with the AR interfaces, which required users to become proficient with the devices. The initial exploration was limited to simple 3D shapes, while more complex, organic forms needed advanced algorithms and expertise beyond that of a designer, specifically calling for an expert coder to fully utilise 3D visualisation capabilities for organic models.

This study found that focusing on AR and AI algorithms and integrating technology into industrial design education enhances learning. AR integration with 3D model development supports industrial design education. This method could transform design education by enabling students to create more models in less time, optimising resources, and fostering creativity. Future implications: This study examines industrial education using AR technology and backs its claims with empirical data. This approach helps industrial students to understand and visualise.

The study investigates the use of augmented reality in industrial design education, supported by empirical data. AR enhances students' understanding of complex designs. A novel AR collaborative system with AI is introduced for design education. This system enables learners to easily modify virtual models. The software can extract data from models for seamless transition between sketching and digital work. Future developments should incorporate AI and AR techniques. AI methods like distance mapping can improve model quality. Design firms should invest in these technologies for rapid 3D model creation. Educators ought to implement AI-driven techniques in design education. Collaboration between designers and AI experts is vital for achieving educational aims. Educators should adopt AI-driven methods in design education (Kaplan et al., 2021). To advance industrial design teaching, educators need to implement AI-driven techniques. It is crucial for designers and AI specialists to work together to meet educational objectives.

7 Chapter 7. Conclusion

Chapter Summary: The thesis examines the difference between using traditional 3D software and virtual and augmented reality (AR) in learning and engagement, enjoyment and acceptance, for industrial design students in the context of three-dimensional model making. Results showed that AR was more effective than both traditional and VR methods in terms of levels of engagement. The findings indicate that AR outperformed traditional and VR approaches in terms of perceived involvement (M_{AR} = 4.04, SD_{AR} = 0.21), enjoyment (M_{AR} = 4.16, SD_{AR} = 0.36), and acceptance, with significant statistical differences when compared to the other two modalities. AR's immersive interface effectively reduced cognitive load, enabling more efficient learning experiences and faster design iterations. While the study faced limitations, including a lack of heterogeneity in the sample and constraints in algorithm expertise, it underscores the value of AR in fostering sustainable design practices by minimising material waste during prototype development. Additionally, the integration of AR and AI demonstrates significant potential for transforming design education by personalising learning experiences, optimising resources, and refining pedagogical strategies. Future research should aim to include a more diverse demographic, evaluate long-term learning outcomes, and enhance the integration of AI and AR technologies to expand their applicability in educational settings...

Keywords – AR, Design, Immersive Experience, Traditional Learning, Virtual Reality,

7.1 Comparisons among Traditional 3D software, Virtual Reality (VR), and Augmented Reality (AR)

7.2 Perceived Engagement

A comparison of Traditional 3D software, Virtual and Augmented Reality was conducted using perceived engagement as the metric. The findings indicate that the standard deviation for traditional 3D software is "0.47" with a mean of "3.52". However, differences were observed in the calculation for VR and AR, with standard deviations of "0.81" and "0.21", respectively. Significant results were recorded in learning engagement linked to the variations in 3D modelling for software development, with the comparison yielding "(Conventional Vs VR Vs AR)" [F (2,112) = 9.499; p = 0.0002]. Due to the average value for the perceived learning engagement being highest in the case of AR application, the result is "(M_{AR}= 4.04, SD_{AR}= 0.21)" (Eastman et al., 2021). Thus, the data suggest that

Table 7.1 Perceived Engagement VR Vs AR

Perceived Engagement			
MODE	**N (Count)**	**Mean**	**Std. Deviation**
Traditional 3D Software	34	3.52	0.47
VR	34	3.88	0.81
AR	55	4.76	0.43

Notably, only 5% of students expressed strong opinions the AR applications provide the highest perceived learning engagement for the creation of 3D model prototypes for industries, students, or learners about perceived engagement, while the remaining 95% indicated agreement with this parameter. (As summarised in Table 7.1)

7.3 Perceived Enjoyment

For perceived enjoyment, AR applications achieved an N count of 55, including a mean score of 4.16, which provides a standard deviation of 0.36. Variations in 3D software resulted in notable differences in perceived enjoyment,

Table 7.2 Perceived Enjoyment VR Vs AR.

Perceived Enjoyment			
MODE	**N (Count)**	**Mean**	**Std. Deviation**
Traditional 3D Software	34	3.5	0.63
VR	34	4.19	0.52
AR	55	4.16	0.36

as indicated by "[F (2,112) = 21.387; p = 0.0001]". AR showed a higher average value compared to traditional 3D software, underscoring its effectiveness in enhancing the enjoyment of learning 3D among design students. While 16% of students strongly agreed with perceived happiness, the remaining 84% expressed moderate agreement (As shown in Table 7.2)

7.4 Perceived Acceptance

Differences in perceived acceptance due to variations in 3D software model were quite evident. Industrial design students demonstrated the highest acceptance rates for AR applications. The standard deviations for 3D, VR and AR were 0.17, -0.88, and 0.43, respectively, highlighting a clear gap. 75% of students strongly supported the use of AR, while the rest 25% expressed agreement. (As shown in Table 7.3)

Table 7.3 Perceived Acceptance VR Vs AR

Perceived Acceptance			
MODE	**N (Count)**	**Mean**	**Std. Deviation**
Traditional 3D Software	34	2.94	0.17
VR	34	4.12	0.88
AR	55	4.76	0.43

7.5 Cognitive Load

Studies have shown that AR-based arrangements outperform traditional methods due to features such as accessibility and ease of use. AR also reduces cognitive load, contributing to a more engaging user experience. Participants reported lower cognitive demands with AR devices, prompting a really captivating encounter. Participants reported lower cognitive demands with AR, as indicated by "NASA Task Load Index" scores below 2.5. Scores above 3.5 reflected positive feedback regarding framework acceptance, usability, and enjoyment (Dorta, 2007). By combining conceptual and narrative reviews, Lavrsen and Daalhuizen (2024) investigate cognitive load in design work. To improve efficiency and creativity, they examine how designers manage cognitive demands. The study provides insights for improving design processes by highlighting techniques for striking a balance between intrinsic, extraneous, and germane cognitive loads. (Lavrsen and Daalhuizen,.2024). Reduced cognitive load in AR environments further enhanced engagement and facilitated learning in 3D model creation (refer to Figure 7.1). Hence, the AR-based

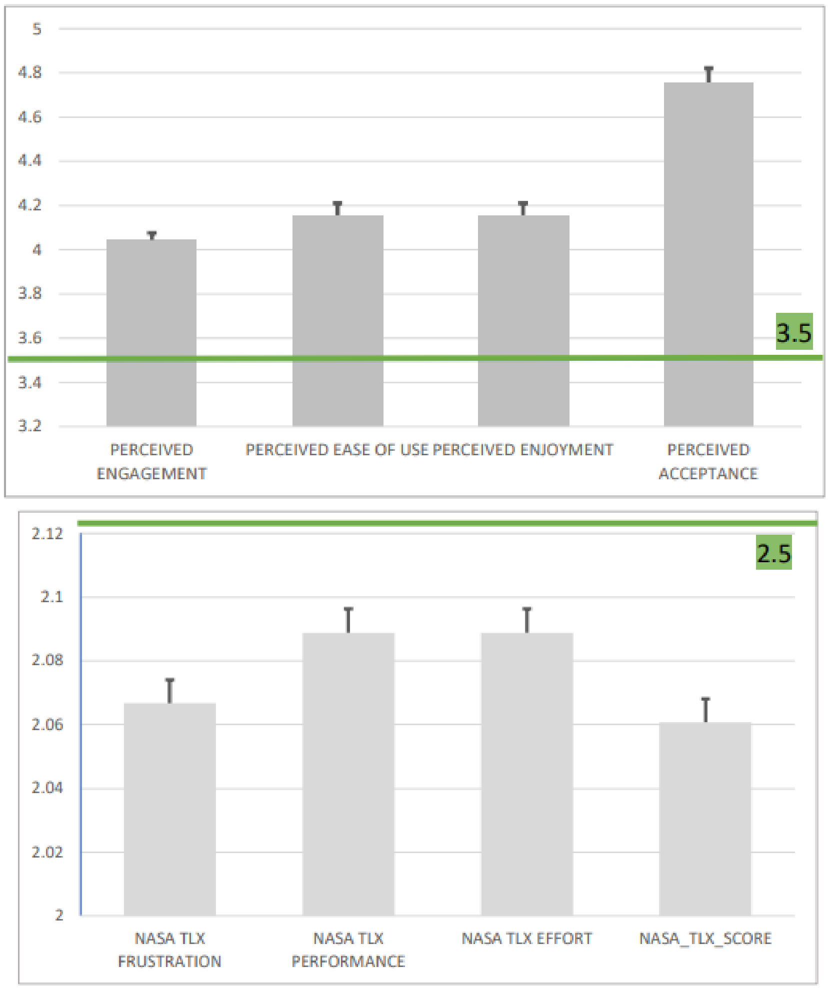


Figure 7.1 NASA-TLX - Perceived Parameters - Standard deviation with Standard error

system has more potential than VR based system. (shown in Figure 7.2)

7.6 Statistical Inference for Hypothesis Testing

A statistical analysis was conducted to assess the effectiveness of AR innovation. The findings suggest that compared with VR and customary cycles, AR offers slightly enhanced learning opportunities for students in industrial design towards modern planning (Fraga-Lamas et al., 2018). The elective hypotheses (Ha2, Ha3, and Ha4) were validated, and the null hypotheses were rejected with *p*-upsides of 0.0002 and 0.0001, for comparison against standard 3D programming and VR. These results strongly support the role of AR in promoting higher levels

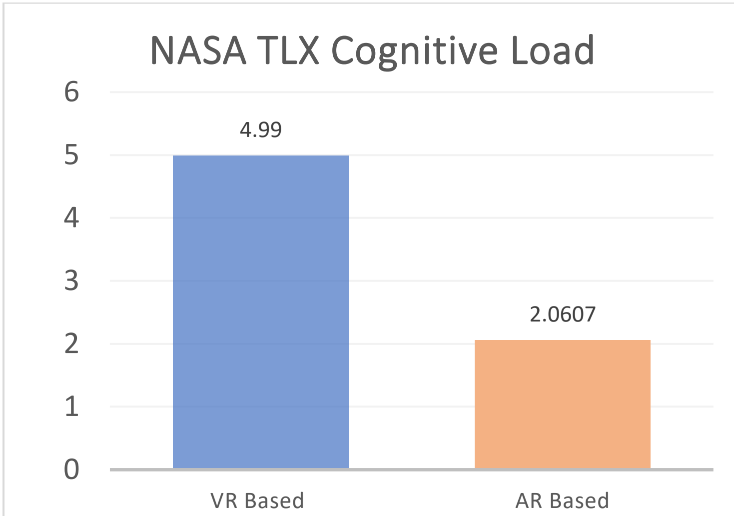


Figure 7.2: NASA-TLX - VR based in comparison to AR based cognitive Load

The study of acknowledgement, enjoyment, and engagement in 3D model-making activities (Refdinal et al., 2023) highlights that AR technology is a highly effective tool for advancing design education, demonstrating its capacity to engage students more deeply compared to both VR and traditional methods. Egger and Masood (2020) analysed the application of augmented reality (AR) in the context of Industry 4.0 and smart manufacturing. Their research showed the importance of AR in employee training and in assisting with maintenance and production processes through its step-by-step guides and real-time information provision. The review also highlighted issues of implementation, together with some research gaps, and addressed some benefits, such as improved information processing and reduced operational mistakes, as well as improved productivity. The findings emphasised the growing role of AR technology in the evolution of intelligent manufacturing systems (Egger & Masood, 2019)

7.7 Conclusion

AR and VR differ significantly in their levels of immersion, which subsequently affects human perception and adaptability to virtual environments

Figure 7.3 Design students trying their hands on proposed AR intervention on 3D model visualisation (Image source: Author and Priyanshi V. 2024, IMD Lab)

(Mills & Brown, 2021). The arrangement of computer-generated reality can speed up the planning for iterative insights and examples analysed by the architects, utilising the actual presence and examinations separately. While VR facilitates the creation of entirely virtual environments, providing a fully immersive sensory experience, AR enhances interaction by overlaying digital elements onto the physical world (Wang, 2007). AR bridges the digital and real worlds by integrating 3D images, enabling more interactive communication between the two realms (Checa et al., 2021). In contrast, VR often requires external controllers or devices, which may limit direct interaction within the virtual environment.

This study aimed to examine the impact of immersive technologies, especially AR and VR, on design education and 3D modelling processes. The findings highlight the potential of AR to optimise resources for design institutions and speed up project delivery by enabling faster iterations of 3D models. If supported by empirical evidence, integrating AR as a standard tool in design education could transform teaching methods (Patra et al., 2022). Additionally, the research emphasises the importance of combining Artificial Intelligence (AI) and Augmented Reality (AR) technologies to improve the educational experience, providing tools that engage students and enhance visualisation. Based on the research findings, the following recommendations are proposed for students and educators in design education:

1. **Adopting AR Technologies:** Leverage the use of AR applications to enhance learning outcomes in industrial design education. Encourage students to explore and utilise AR tools to enrich their learning experiences and foster innovation.

Table 7.4 Summary of the Hypothesis of the thesis

Alternative Hypothesis	Significant Difference	Accepted/Rejected	Remarks
H1: Industrial design students utilising AR technology for 3D modelling will demonstrate greater levels of learning engagement compared to those using traditional 3D software.	There is a significant difference	Rejection of Null Hypothesis $p = 0.0002$	Hypothesis established
H2: Industrial design students using AR technology for 3D model-making show greater learning engagement than those utilising VR technology.	There is a significant difference	Rejection of Null Hypothesis $p = 0.0001$	Hypothesis accepted
H3: In comparison to use of VR, industrial design learners using AR technology for 3D model-making will exhibit higher levels of learning engagement.	There is a significant difference	Rejection of Null Hypothesis $p = 0.0001$	Hypothesis established

2. **Regular Practice with AR Applications**; Incorporate regular practice sessions using AR-based tools to improve skills in 3D visualisation and

iterative creation. Consistent practice will help students refine their design abilities and build familiarity with AR technologies. (Refer to Table 7.5)

AR for Iterative Design: Students are encouraged to utilise AR technology for iterative design processes, emphasising its ability to quickly generate and visualise multiple design iterations. This approach accelerates and enhances the effectiveness of design enhancements. Many design courses in the curriculum are lab-based and require proficiency in tools and motor skills. These courses demand that students develop both dexterity and cognitive abilities. AR-based solutions can assist students in visualising 3D models and producing numerous iterations by following these recommendations; both educators and students can utilise AR tools to improve academic outcomes in industrial design courses in less time. Educators can integrate AR into classes like Model Making, Prototyping, and Form and Space to enrich the learning experience.

The integration of AR in 3D visualisation enables design students to overcome limitations in prototype representation, enhancing their decision-making before producing a final physical model. AR enables precise visualisation of shapes and forms, reducing material wastage and promoting sustainability. This greatly contributes to eco-friendly and resource-efficient industrial design education.

Integrating AR and AI into design education has the potential to change both the epistemological and ontological dimensions of 3d. Epistemology, the study of knowledge and its justification (Hofer, 2001), investigates how knowledge is gained and utilised. Egunjobi and Adeyeye (2024) explored how augmented reality (AR) and artificial intelligence (AI) are influencing education, affecting both the ways students learn and their interactions with their environment. They pointed out that this integration improves complex understanding and awareness of one's epistemological thinking processes. The authors also stressed the importance of the transformation resulting from interactions between the physical and virtual realms, particularly in relation to design education dependent on three-dimensional models and visualisation graphics (Egunjobi and Adeyeye, 2024). Zhou and Park (2023) explored the role of AI-powered sketches and cognitive support for conceptual design. A novel multimodal machine learning model is developed, evaluated against alternatives, and trained using curated data to strike a balance between fidelity and diversity. AR and AI (Artificial Intelligence) have created new opportunities for educators to craft lessons that are more personal, engaging, and effective, while remaining aligned with the latest trends in design education.

In the coming years, it will be essential for researchers to examine how these technologies impact student learning over time and to develop practical ways to integrate them into teaching. For example, a study by Ghazali et al. (2021) showed that AR can play a valuable role in engineering education by helping students understand and remember complex concepts more effectively. This study also investigates how AR and AI improve 3D modelling skills in industrial design students. Through immersive interactions, AR reduces cognitive load, while AI provides intelligent feedback, automates routine tasks, and personalises learning. These technologies enhance students' understanding of design principles and their real-world applications, changing how they interact with digital models. Faculty members can use AR to give remote feedback on students' 3D visualisations at their convenience, simplifying the assessment process.

7.8 Limitations

The study highlights the potential of integrating AR and AI into industrial design education to improve learning outcomes. AR's combination with 3D model development supports industrial design learning and introduces an innovative collaborative system featuring AI. Features such as intuitive interfaces enable learners to visualise and modify virtual product models easily, extracting vertex and edge data to transition smoothly between sketching and digital (Sadiku et al., 2020). These capabilities help optimise resources in design institutions, accelerate project timelines, and provide diverse design options. However, the study also faced limitations. Time and resource constraints affected the scope and accuracy of the results. The study lacked extensive expertise in algorithm design and had a limited demographic reach due to a small sample size. These factors restricted the ability to generalise findings to all design students.

7.9 Future scope

This research paves the way for further exploration of the broader role of AR and AI in the design process. Future studies should focus on long-term learning outcomes, such as skill retention and real-world application. AR-based integration offers greater flexibility in creating and visualising 3D models, and additional research on interaction models and user interface design for AR in classrooms could improve accessibility and engagement (Venkatesan et al., 2021). Rafael and Silva (2022) propose that constructing a 3D model from multiple views requires precise alignment and mapping of those views. By correlating extracted vertex and edge data, they map orthographic views and identify sets of vertices forming closed contours, representing 3D planes. Future directions should include the integration of AI and AR technologies. AI tools like distance mapping and edge recognition can enhance model quality, while larger sample sizes will provide more robust and relatable data. Expanding the scope to analyse immersive technology across different subject areas could yield diverse perspectives. Educational institutions should invest in resources to support curriculum development, while design organisations should adopt these technologies to empower students in creating 3D models efficiently (Kaplan et al., 2021; Kuhail et al., 2022). To improve education systems in industrial design, a strategic and technology-driven approach should be integrated into curricula. Collaboration with AI experts will be essential to advancing learning processes and achieving effective outcomes.

This chapter examines how AR and VR are increasingly influencing the way design is taught, making the learning journey—especially in 3D modelling—more engaging and inspiring. AR emerged as the most effective technology for encouraging engagement, enjoyment, and acceptance among students, providing intuitive tools that reduce cognitive load and enhance design iteration processes. In conclusion, this chapter encourages design educators and institutions to adopt emerging technologies. By adopting AR and AI thoughtfully, we can transform design education into a more innovative, sustainable, and inclusive discipline that empowers the next generation of creative thinkers.

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List of Publications

Shakti Banerjee
ORCID ID : 0000-0003-4176-2418

Sr	Name of Publication	Authors	Indexing	Status	ISSN / ISBN number
1.	Banerjee, S., Chowdhury, A., & Yein, N. (2023). User Experience Evaluation of a Virtual Reality Tool Used for 3D Modelling in Industrial Design Education: A Study in the Indian Context. Designs, 7(5), 105.	First	Journal - SCOPUS	Published in 2023	https://doi.org/10.3390/designs7050105
2.	Banerjee, S., Srivastava, A., & Chowdhury, A. (2021, December). Application of Immersive Media to Develop Model Making Skills of Industrial Design Learners. In International Conference of the Indian Society of Ergonomics (739-750). Cham: Springer International Publishing.	First	SCOPUS	Published in 2022 Springer	Print ISBN 978-3-030-94276-2
3.	Banerjee, S., Chowdhury, A., & Srivastava, A. (2021). Creating awareness about health and hygiene during menstrual cycle among Indian adolescent girls using virtual reality. In Advanced Manufacturing Systems	First	SCOPUS	Published in 2021 Springer	ISBN : 978-981-15-9852-4

	and Innovative Product Design: Select Proceedings of IPDIMS 2020 (327-339). Springer Singapore.				
4.	Banerjee, S. (2021). Strategies for Design and Development of Serious Games: Indian Perspective. In Encyclopedia of Computer Graphics and Games (1-7). Springer, Cham.	First		Published in 2021 Springer	https://doi.org/10.1007/978-3-319-08234-9_404-1
5.	Creating Artificial Learning Environment on Wood Turning Lathe Machine for Training Design students using Virtual Reality. S Banerjee, D Maheshwari, & A Chowdhury. ACED 2023, BRICSplus HFE 2023 and HWWE2023, IIM, Mumbai	First	SCOPUS	Accepted & Presentation done in ACED conference - 16 Dec, 2023 Going to publish in 2024	
6.	Application of AR for 3D Products Visualisation and Enhancement of Learning Engagement of Industrial Design Learners. Banerjee, S., Yein, N. & Chowdhury, A., ICoRD’25, Indian Institute of Technology Hyderabad. (IIT)	First	SCOPUS	**Paper has been presented 8 January, 2025 at ICorD, going to publish in 2025**	ICoRD Jan2025

Awards conferred to the research output of this thesis

- The paper on Application of Immersive Media got awarded with BEST DISTINGUISHED PAPER at HWWE 2021 conference.
  Title of the paper: Application of Immersive Media to develop Model making skills of Industrial design learners.
  Published in 2022, Springer, Scopus indexed.

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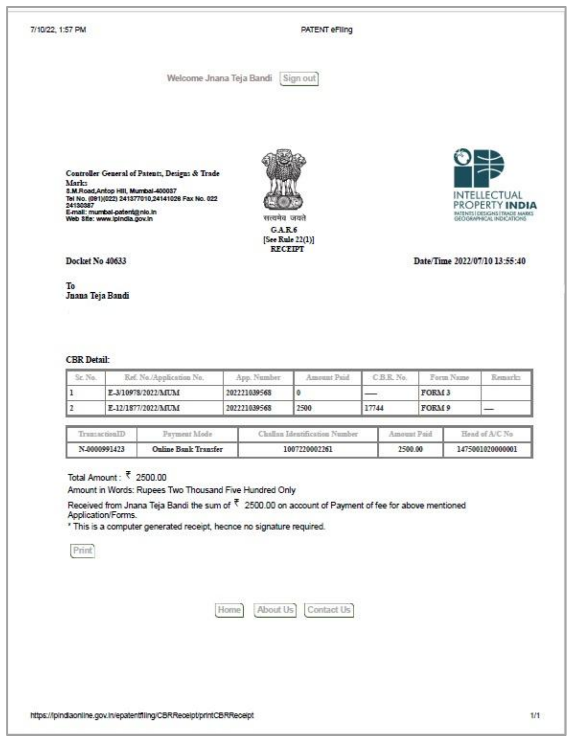

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Appendix A

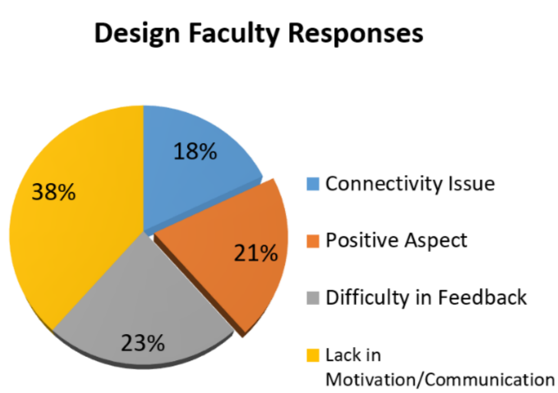
Scope of the Initial Reasoning of the Thesis Work

Overview Design Pedagogy Overview

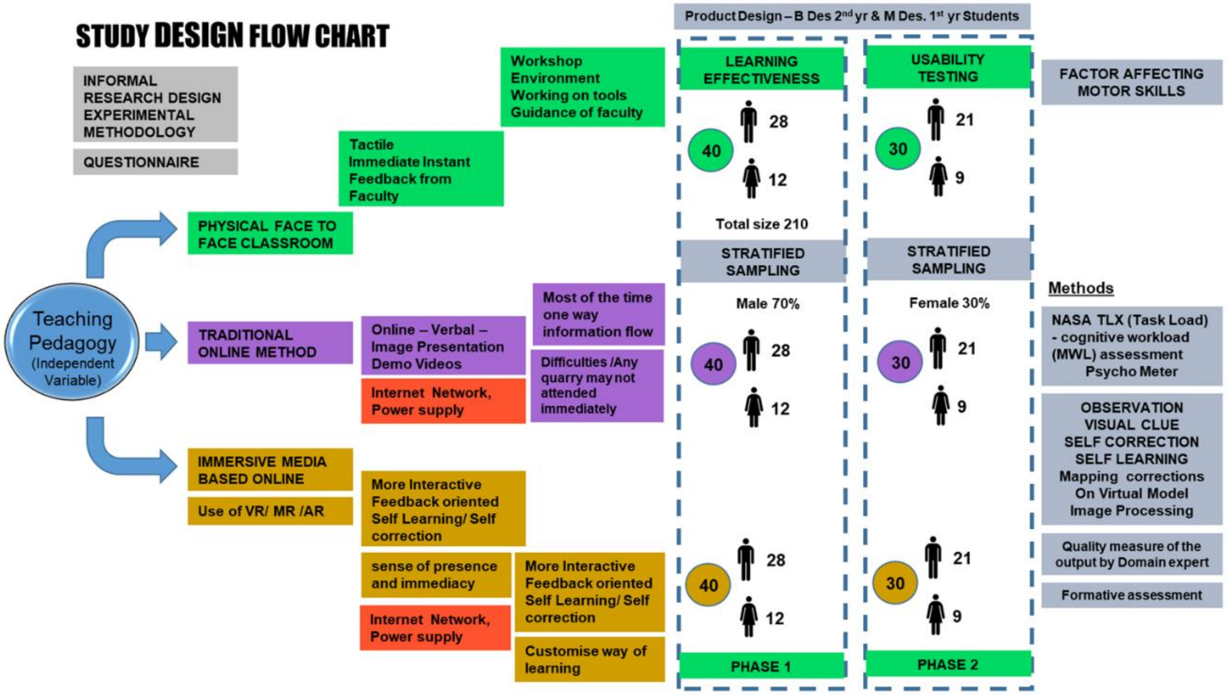
This thesis investigates the complex landscape of design education and their teaching approaches. Design pedagogy adopts a practical approach to the curriculum. Design education covers diverse subjects, including skill-based, cognitive, workshop-based, project-based, and technical courses. During the Covid-19 pandemic, design institutes transitioned to online teaching, adapting hands-on curricula to virtual platforms. This shift provided insights into student and faculty experiences, emphasising the importance of managing cognitive load in online sessions.

Design pedagogy emphasises practical engagement alongside theoretical learning. Under faculty supervision, students develop prototypes and models, honing motor and soft skills. Key components include:

- Skill-based Learning: Focuses on fundamentals like drawing, visualisation, model-making, and rendering, emphasising precision and technique.
- Cognitive-based Learning: Builds critical thinking to prioritise effective decision-making.
- Project-based Learning: Integrates skills and concepts, fostering contextual application.



Faculties Responses from various Design Institute
1. MIT Institute of Design
2. School of Design –UPES
3. DYPD, Pune



Foundation year Student's Responses

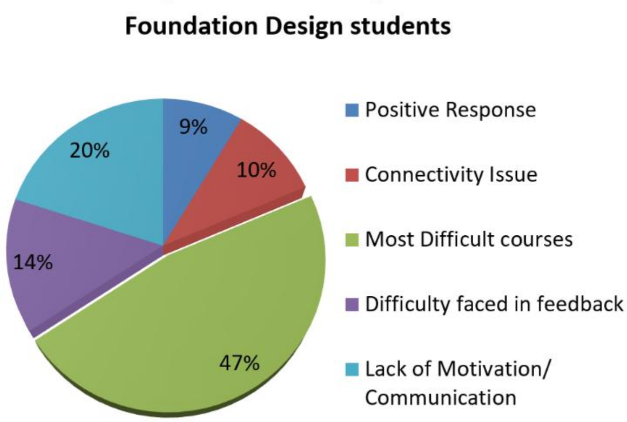
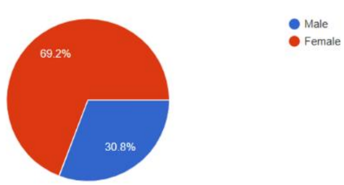


Figure 4. Pie Diagram



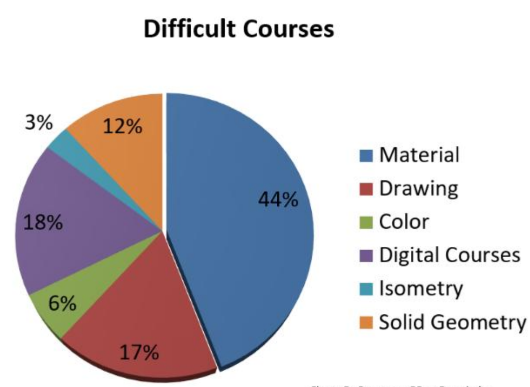


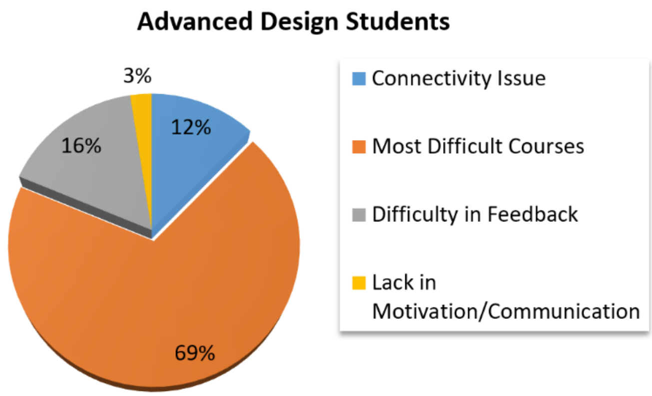
Figure 5:. Responses BDes Foundation

Foundation Design
B Des 1st yr

Sample size 30

MIT Institute of Design, Pune

Advanced year Design Student’s Responses



MOST DIFFICULT COURSES

- Design for special needs
- Prototyping
- Technical product design, electronics
- Furniture course
- Clay modelling
- Space design
- Material course
- Proportions in 3D
- Product Sketching Course
- Rendering
- Packaging
- Way finding
- Field study

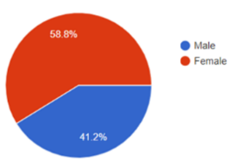


Figure 7:. Response Advanced students

Advanced Design
B Des 2nd,3rd & 4th / Mdes 1st & 2nd

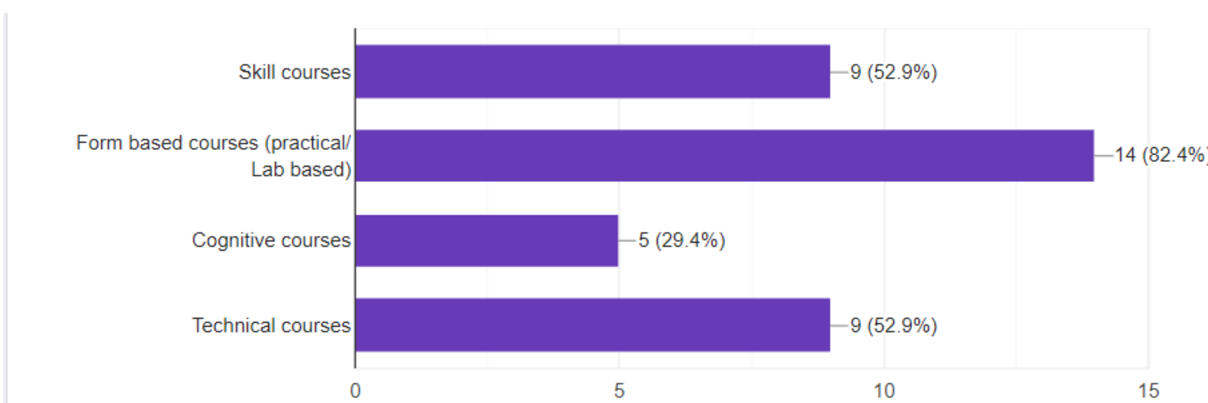
Design students of Industrial Design – Product design (PD), Transportation Design (TD), Interior Space and Furniture (ISFD) & UED

Sample size 47

MIT Institute of Design, Pune
School of Design, UPES, Dehradun
National Institute of Design, Bangalore

MOST DIFFICULT COURSES

Which course did you faced more problems in explaining the subject in online design education?



Experimental Research

The research is exploratory Probability sampling **Stratified sampling**

Sampling done of BDes & Mdes Industrial design students – Product design, Transportation Design, Space & Furniture, Innovation, UX design etc.

Sample member have prior knowledge of Model Making/ Prototyping. Knowledge of basic 3D modelling software such as Fusion/Blender/ 3D Max/ Maya/ sketchup, etc.

3D model making using traditional 3D software

Pre Task – Conventional 3D software Questionnaire

3D model making using VR based 3D modelling software

Independent Variable

VR Lab

Control Environment

Apparatus : Meta Quest 2

Dependent Variable

learning Experience

Parameters kept

1. Perceived Usability
2. Engagement
3. Enjoyment while using
4. Time consumed for creating 3D models

Compared results statistics

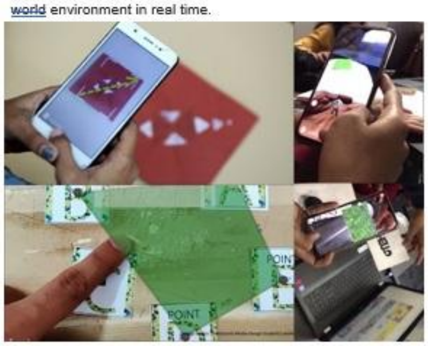
Study of 3D concept visualistion experience of industrial design learners using Virtual Reality

Thank you very much for your contribution to participate in this important research study to improve the learning experience of students in design lessons.

This short questionnaire is a part of a PhD research work being conducted on "Eficiency of immersive media in developing motor skills among learners in online education in industrial design". The aim of the research is to enhance the practical learning experience of students by making use of emerging technologies/media like Augmented Reality (AR) and Virtual reality (VR). This questionnaire will help in designing systems and formulating guidelines to achieve these goals to make student's learning experience engaging and easy.
This survey should take only 5-7 minutes to complete. All personal information provided by you in this questionnaire will be kept confidential and I assure you that participants will be kept non traceable and anonymous. The names of the participants have only been taken for follow –up interview if required.
The questionnaire does not to access your marks, intelligence or knowledge.
Once again, thank you for participating in this research study and giving us your precious time.

Shakti Banerjee
PhD Research Scholar
School of Design
UPES

AUGMENTED REALITY (AR) The basic idea of Augmented Reality is to augment computer generated 3D, graphics, audio and other sensory enhancements over a real-world environment in real time.



VIRTUAL REALITY (VR) refers to a computer-generated simulation in which a person can interact within an artificial three-dimensional environment using electronic devices, such as special goggles with a screen or gloves fitted with sensors. In this simulated artificial environment, the user is able to have a realistic-feeling experience.

Applications of Virtual reality in various domains

Immersive Media: Immersive media is defined by immersive technologies that attempt to create, or imitate the physical world through digital simulation. It is the coming

9. Do you have any knowledge of 3D modelling before? *

YES

NO

10. If YES, 12. Which 3D software tools are you very fluent with? *

Check all that apply.

- 3D Max
- Solidworks
- Blender
- Maya
- Sketchup
- Rhino
- Fusion
- Other:

11. Perceived Use of use (PEoU)
PEoU *
1 Conventional 3D software like Fusion, Solidworks, Blender, 3DMax, etc. are easy to use to create 3D bottle.

Mark only one oval.

Strongly Disagree -1

Disagree -2

Uncertain-3

Agree -4

Strongly Agree -5

1/5/23, 6:02 PM Efficiency of immersive media in developing motor skills among design learners in industrial design education

6. 5. Discipline *

Mark only one oval.

Product Design PD

Interior Space and Furniture Design ISFD

Transportation Design TD

Retail Design RED

Immersive Media Design IMD

Automotive Sculpting - Digital & Clay

Graphic Design GD

Communication Design

User Experience Design UED

Animation Design

Innovation Program - MITID

Other:

7. Have you experienced the online mode of education in your respective field of study? *

Mark only one oval.

YES

NO

8. How was the experience of online class? (with reference to learnings) *

Mark only one oval.

Least Likable -1

2

3

4

Most Likable -5

12. Perceived Use of use (PEoU)
PEoU 2 It is very easy to learn in conventional 3D software to create 3D Models.

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

13. Perceived Use of use (PEoU)

PEoU 3

The text information of measurements on the screen makes at ease to create 3D Models

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

14. Perceived Engagement (PE)

PE 1Tasks can be performed in a straightforward manner using conventional 3D software

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

12. Perceived Use of use (PEoU)
PEoU 2 It is very easy to learn in conventional 3D software to create 3D Models.

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

13. Perceived Use of use (PEoU)

PEoU 3

The text information of measurements on the screen makes at ease to create 3D Models

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

14. Perceived Engagement (PE)

PE 1Tasks can be performed in a straightforward manner using conventional 3D software

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

15. Perceived Engagement (PE)

PE 2 Creating 3D model using conventional 3D tool is very engaging.

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

16. Perceived Engagement (PE)

PE 3 - Engrossing with precision in creating 3D models in conventional 3D software such as Blender, Fusion, 3D max etc.

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

17. Perceived Fun Aspect (PFA)

PFA 1 - I am able to visualise in the spatial in conventional 3D software.

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

18. Perceived Fun Aspect (PFA)

PFA 2 - It was fun to explore 3D model in conventional 3D software

Mark only one oval.

- Strongly Disagree -1
- Disagree -2
- Uncertain-3
- Agree -4
- Strongly Agree -5

19. Time in minutes consumed in any conventional 3D software for the same simple Bottle (Assignment 1) model? *

20. Do you recommend use of VR in model making course? (as per your knowledge so far) *

Mark only one oval.

- NO
- Uncertain
- YES

32. Overall, what's your experience been with VR – Gravity Sketch? *

Very fun experience, it does take some time to learn and get used to the controls.

33. Any Suggestions and observations after the use of VR? *

The usage takes a heavy toll on eye and beginners might have problem to interpret while creating models in Gravity sketch

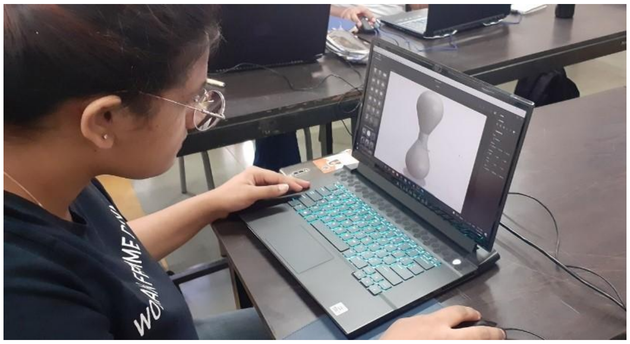
Appendix B

PARAMETERS	
Parameter	**Statement**
Perceived Engagement (PE)	
PE 1	Creating 3D model by using AR tool is very engaging.
PE 2	Task can be performed in a straightforward manner and easily engaging
PE3	It was very intuitive in nature to explore 3D model using AR tool and easy to engage
Perceived Learnability (PL)	
PL 1	Perceived learnability increases as the AR system easy to understand to perform the task.
PL 2	Perceived learnability in easy to visualise 3D models.
PL 3	Perceived learnability in able to visualise in spatial using AR tool.
Perceived Ease of use (PEoU)	
PEoU 1	By using AR based instructions, visualisation of creating 3D model of creating a bottle is easy to use.
PEoU 2	Learning to use the AR system is not a problem.
PEoU 3	Operation with the system is clear and understandable. Using gestures controller makes at ease in AR to create 3D Models
Perceived Enjoyment (PE)	
PE 1	I enjoyed using the AR system which helps to visualise the 3D form fast
PE2	The interface of the AR System is pleasant and joyful
PE3	Feel Satisfied with how easy it is use the AR based system for 3D visualisation
NASA-TLX	

NASA-TLX Temporal	Found the AR system mentally demanding and thus takes more time
NASA-TLX FRUSTRATION	After using AR based Instructions method for creating 3D Model,found the AR system was frustrating.
NASA-TLX PERFORMANCE	Difficult to perform the task
NASA-TLX EFFORT	Need to put lots of Effort
PERCEIVED ACCEPTANCE	
PA 1	Instead of switching between a CAD model and a mockup material model, using augmented reality to explore a 3D model was incredibly intuitive.
PA 2	Believe that using such AR system in the 3D model making is a good idea.
PA 3	Able to do final visualisation of form and shape of the intended 3D using this AR system before creating mockup model using material like MDF, Foam etc. Thus, it helps to prevent wastage of materials that helps in sustainability.

Appendix C

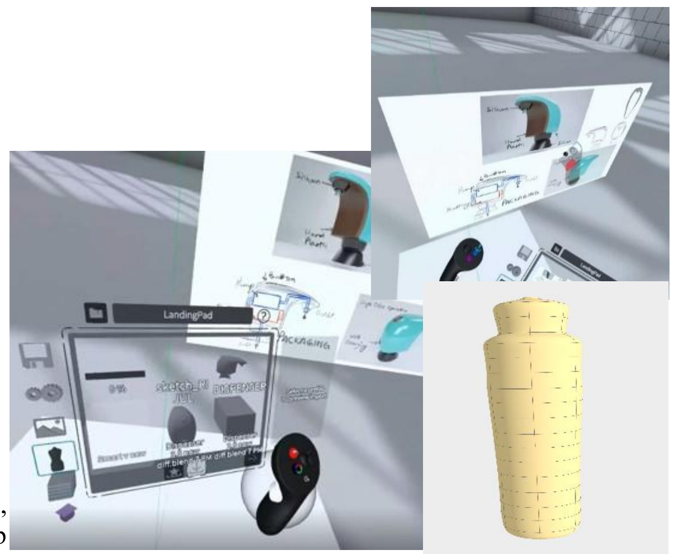
Photographs and Screenshots during the study of Experimental research for various stages of exploring AR and VR for 3D model making
3D software, Meta Quest2, Gravity Sketch, Vuforia,ARcore



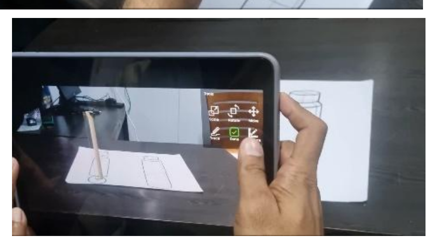
Using Traditional 3D software (Image source: Student Rhea Mudhgar, 2022), IMD Lab

Using VR based

(Image source: Author, 2022), IMD Lab



Using AR based



(Image source: Akshay Alvankar, 2023), IMD Lab)

Shakti Banerjee

EFFECTIVENESS OF IMMERSIVE MEDIA TO ENHANCE 3D MODEL MAKING AMONG INDUSTRIAL DESIGN LEARNERS IN...

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