Thesis Proposal

Evaluating the outcome of XR Mind Mapping Applications with Emotional Intelligence and Stress Level: A Systematic Review on MindPool, Noda, Softspace and XMind

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I have read the attached thesis proposal and, in my opinion, it proposes work which is adequate in depth and scope to serve as the culminating experience for the Master's Degree in Computer Science. I would agree to chair this committee or serve thereon.

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# ABSTRACT

Mind mapping is a widely adopted technique for visualizing ideas and fostering creativity, with applications in education, productivity, and personal organization. As Extended Reality (XR) emerges as a powerful medium for immersive ideation, understanding its impact on users' emotional and cognitive states is crucial. This study investigates user stress levels, cognitive load, and emotional intelligence across four mind-mapping platforms: MindPool, a custom-developed XR application; two existing XR-based tools, Noda and Softspace; and the 2D mind-mapping application XMind. By comparing these platforms, the research explores how the immersive qualities of VR influence stress, productivity, and creativity during mind-mapping tasks.

A mixed-methods approach is employed, integrating biophysical measurements and self-reported feedback to evaluate user stress and performance. Sentiment analysis using natural language processing (NLP) is applied to categorize mind-mapping outputs into problem-oriented and solution-oriented outcomes. The study examines the relationship between immersion, user experience, and task performance, with a focus on the interplay between stress levels and productivity.

Preliminary findings suggest that XR-based tools enhance engagement and creativity but are associated with higher stress levels compared to 2D platforms. This research provides valuable insights into the emotional and cognitive effects of XR in individual workflows, offering practical implications for designing immersive tools that minimize stress while optimizing productivity in mind-mapping processes.

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# INTRODUCTION

Productivity is a crucial factor in both personal and professional success, and individuals across various domains constantly seek ways to enhance it. In academia, one of the methods commonly employed to increase productivity, especially during the research and paper-writing process, is the use of mind maps. Traditionally, mind-mapping has been confined to 2D applications, which have become widespread due to their accessibility and simplicity.

However, 2D mind-mapping applications have notable limitations. They can quickly become cluttered, are restricted by two-dimensional space, and often constrain creativity. Emerging technologies, such as Virtual Reality (VR), offer the potential to alleviate these limitations by creating immersive, three-dimensional environments that provide greater spatial flexibility and more intuitive interactions.

Despite the advantages of VR mind-mapping applications, such as increased space and improved ease of use, these tools are still in the developmental stage. Currently, there are only two prominent VR mind-mapping apps: Noda and Softspace. Both applications, however, come with their own set of limitations. For instance, Noda lacks expandable notes and has a challenging user interface for mind mapping, while Softspace focuses exclusively on notetaking with limited mind-mapping functionalities and relies more on hand tracking compared to controller usage which is prone to lower usability.

In response to these limitations, this study introduces a novel, self-developed VR mind-mapping application called MindPool. Designed and built specifically to address the challenges faced by existing VR and 2D mind-mapping tools, MindPool offers a more comprehensive solution tailored for academic researchers and other users who rely on mind-mapping to enhance productivity. By incorporating features that extend beyond the capabilities of its competitors, MindPool aims to push the boundaries of what mind-mapping applications can achieve in a virtual environment.

# LITERATURE REVIEW

## 2.1 Notetaking

Notetaking is a widely used learning method that enables individuals to document information from various fleeting sources such as lectures, discussions, and meetings. This method helps learners to offload information from their minds, making it easier to recall later [1]. Traditionally, notes were handwritten, but with technological advancements and the rise of notetaking software, a shift toward digital notetaking has emerged among both students and professionals.

Notetaking is considered an essential skill for students from primary to higher education levels, primarily to record key information delivered during lectures. This documentation helps students when reviewing concepts, preparing for exams, or sharing information with peers. Several studies [2], [3], [4] have demonstrated that notetaking enhances students' engagement during lectures and improves their understanding. Interestingly, even students who do not refer to their notes while studying tend to perform better than those who do not take notes at all. This positive effect is even more pronounced when notes are handwritten and paraphrased, as opposed to being transcribed or typed verbatim.

### 2.1.1 Notetaking Versus Note-Making

Notetaking and note-making are often used interchangeably, but they differ in many ways. Notetaking refers to the process of recording information as it is received, such as during a lecture or meeting. It is typically a passive activity that focuses on capturing facts, keywords, and details. In contrast, note-making involves a more active engagement with the material, where the individual synthesizes, rephrases, and organizes information to aid understanding and retention.

Several studies highlight the cognitive benefits of note-making over traditional notetaking. For instance, research by [5] suggests that students who engage in note-making tend to achieve higher academic performance because they are processing information at a deeper level. By actively reconstructing knowledge, learners create mental links that improve recall and comprehension.

### 2.1.2 Notetaking Methods

Various methods of notetaking have been developed to enhance the efficiency and effectiveness of capturing information:

* **Cornell Method**: Introduced by Walter Pauk in the 1950s, this method divides the page into three sections: notes, cues, and a summary. It encourages critical thinking by allowing space for questions or key points alongside the notes [6].
* **Mapping Method**: This approach visually represents information, helping users see relationships between topics. It closely relates to mind mapping and promotes spatial organization, making it a suitable method for subjects that require logical structuring [7].
* **Charting Method**: Useful for topics with a lot of data or comparisons, the charting method organizes information into columns, making it easy to compare facts side by side [8].

Studies by [9] suggest that different notetaking methods impact students' comprehension and retention in varying degrees. The mapping method, in particular, has been shown to improve retention by helping students organize and relate information better.

### 2.1.3 Handwritten Versus Computer-Based Notetaking

The debate between handwritten and computer-based notetaking has been widely researched. Handwritten notes have been found to encourage cognitive engagement through the manual process of writing, leading to better retention of information. A study by [10] showed that students who wrote notes by hand had better long-term comprehension compared to those who typed. This is because writing by hand forces students to rephrase and process information instead of transcribing verbatim.

On the other hand, computer-based notetaking offers benefits like speed, ease of organization, and the ability to store and retrieve notes digitally. However, it often leads to verbatim transcription, which may reduce the depth of information processing [10]. Some recent research, like that of [11], points out that while digital notetaking can facilitate quicker information capture, it often lacks the cognitive benefits tied to handwritten methods.

Advantages of Handwritten Notetaking:

* Memorization: Handwriting tends to improve retention of information [10].
* Relevance: Since handwriting is slower, students tend to be more selective and concise [10].
* Flexibility: Handwritten notes allow for more adaptability, especially for complex diagrams or charts [5].
* Fewer Distractions: For some, writing by hand reduces distractions compared to using digital devices [12].

Advantages of Computer-Based Notetaking:

* Speed: Typing is generally faster, allowing for quicker notetaking and structuring of information [11].
* Editability: Digital notes are easier to modify, reorganize, and edit after the fact [2].
* Searchability: Digital notes can be searched efficiently [11].
* Space and Order: Digital notes are more convenient to store and organize than stacks of paper [13].
* Shareability: Digital notes can easily be shared with others [13].

While handwritten notetaking may be better for courses that do not require extensive post-lecture work, digital notetaking offers long-term benefits, especially for courses that involve more detailed revision and cross-referencing.

## 2.2 Mind Mapping

### 2.2.1 Definition of Mind Mapping

Mind mapping is a visual representation technique where ideas, tasks, or concepts are organized around a central theme in a non-linear manner. This method leverages the brain’s natural ability to process and link ideas spatially, aiding both creativity and information retention. According to [14], who popularized the concept, mind mapping stimulates both hemispheres of the brain, enhancing understanding, recall, and idea generation by allowing connections between seemingly disparate concepts.

### 2.2.2 History of Mind Maps

Although Tony Buzan is credited with popularizing mind mapping in the 1970s, the origins of similar concept mapping techniques can be traced back to ancient philosophers like Porphyry of Tyre and Leonardo da Vinci. Buzan formalized mind mapping in his book *The Mind Map Book* (1996), promoting its use as a tool for brainstorming, studying, and organizing information. Early applications of mind maps were manual and relied on handwritten diagrams, but the rise of digital tools expanded their accessibility and usability.

### 2.2.3 Types of Mind Maps

Mind maps can take various forms depending on their purpose and scope:

* Traditional Mind Maps: Centered around a single core idea, with branches representing subtopics.
* Concept Maps: Often used in education, these maps emphasize relationships between different concepts through connecting lines and labels.
* Flow Maps: These maps focus on processes and sequences, illustrating how one step leads to another. They are particularly useful for project planning and task management [15].

The choice of mind map type can influence its effectiveness in organizing thoughts or communicating ideas, depending on the context.

### 2.2.4 How to Make Mind Maps

Making a mind map typically involves a few key steps:

1. Start with a central idea in the middle of the canvas.
2. Draw branches from the central idea to subtopics, which should represent key concepts.
3. Use keywords or short phrases to summarize the subtopics.
4. Incorporate images and colors to make the map visually stimulating and easier to understand.
5. Continue breaking down ideas into smaller, related points [14].

Research has shown that mind maps are more effective when visual elements are used, as these stimulate memory retention and improve cognitive processing [16].

### 2.2.5 Advantages and Disadvantages of Mind Maps

Mind maps offer several advantages:

* Enhanced memory retention: By using colors, shapes, and images, mind maps engage multiple cognitive faculties, improving recall [17].
* Stimulated creativity: The non-linear structure helps in brainstorming and encourages creative problem-solving by allowing free association between ideas.
* Organizational clarity: Mind maps provide a clear overview of complex subjects, breaking them down into manageable parts.

However, they also have limitations:

* Over-simplification: For very complex subjects, mind maps may reduce details, leading to oversimplified representations.
* Time-consuming: Creating detailed, visually appealing mind maps can take time, especially when incorporating images and designs.

### 2.2.6 Applications of Mind Maps in Teaching

Mind maps are commonly used in educational contexts to facilitate learning and comprehension. Instructors often utilize them to:

* Summarize lectures: Providing a visual representation of a lesson's key points.
* Enhance collaboration: Encouraging students to work together on collective brainstorming activities.
* Improve critical thinking: By organizing and synthesizing information, students gain better insights into relationships between concepts [19].

Studies have found that mind mapping increases students’ ability to retain and recall information. For example, [17] found that students who used mind maps outperformed their peers on comprehension and retention tasks.

### 2.2.7 Mind Mapping Tools

In recent years, various digital tools have been developed to facilitate mind mapping:

* MindMaster: A cross-platform and multi-functional mind mapping software, with features like real-time collaboration, cloud storage, and customizable templates [18].
* XMind: A powerful desktop application offering advanced mind mapping features like Gantt charts and integrations with project management systems [18].
* Coggle: A collaborative tool designed for team brainstorming and sharing mind maps easily across devices [15].

The proliferation of digital tools has made mind mapping more accessible and scalable, expanding its applications from individual use to collaborative and organizational contexts.

## 2.3 Mixed Reality

### 2.3.1 Definitions and Overview

A close-up of a card

Description automatically generatedMixed Reality (MR) is an immersive technology that blends the physical and digital worlds, allowing real and virtual objects to coexist and interact in real time, as described by the Milgram Reality-Virtuality Continuum [20]. This continuum, shown in Fig. 1, ranges from a completely real environment to a fully virtual environment. Within this spectrum, mixed reality occupies the intermediary space, where elements of both the real and virtual worlds converge. MR is further divided into augmented reality (AR) and augmented virtuality (AV), depending on the balance between real and digital content. AR integrates virtual objects into the real world with minimal virtual data, while AV introduces real-world elements into predominantly virtual environments, featuring a greater proportion of digital information.

Figure 1: Reality-Virtuality Continuum [20]

While VR immerses users in entirely synthetic environments, MR allows for real-world interaction enhanced with digital content. MR technologies are utilized in various industries such as gaming, healthcare, education, and manufacturing [21]. Devices like Microsoft's HoloLens and Meta Quest support MR, allowing for more intuitive interfaces and spatial awareness in applications.

### 2.3.2 Designing for Mixed Reality

Designing for MR presents unique challenges, as it requires a deep understanding of how users interact with both the real and virtual worlds. The design process needs to account for spatial computing, environmental understanding, and intuitive interaction to deliver a seamless user experience.

Interaction models are a crucial part of MR design. Traditional design principles do not always apply, as MR introduces new modalities, such as gesture recognition, voice commands, and eye tracking. Designers must focus on reducing cognitive load while providing meaningful interactions in hybrid spaces [22].

### 2.3.2.1 Design Process and Mixed Reality

The design process for MR typically involves the following stages:

1. Conceptualization: Defining the use case and how MR can enhance or replace traditional methods. During this phase, designers often consider user needs and the context in which the MR experience will occur [23].
2. Prototyping: Iterative prototyping allows for testing ideas, from low-fidelity mockups to high-fidelity, interactive prototypes. MR-specific tools like Unity, Unreal Engine, and Mixed Reality Toolkit (MRTK) are often used.
3. Evaluation: User testing and feedback collection are critical to refining MR experiences. In MR, users interact with both the physical and digital worlds, so testing across different environments is crucial to account for varying lighting conditions, occlusion, and spatial constraints [24].

### 2.3.2.2 Mixed Reality Design Heuristics

Design heuristics for MR extend beyond traditional usability principles due to the integration of real-world elements. According to [21], key MR heuristics include:

* Spatial Consistency: Ensuring that virtual elements appear naturally within the real-world context. Virtual objects should be correctly anchored and respond to user interactions in expected ways.
* Cognitive Load: Since MR involves multitasking across two realities, designers must reduce cognitive overload by presenting information and tasks in a manageable way.
* Contextual Awareness: MR applications must leverage environmental data, such as object recognition or room mapping, to deliver contextually relevant content.
* Embodied Interaction: Allowing users to use natural gestures, voice, and movement to interact with virtual elements. This enhances engagement and intuitiveness.

Heuristics help ensure that the MR experience is seamless and doesn't overwhelm users, providing a balance between immersion and functionality [22].

### 2.3.2.3 Multimodal Interaction in the Context of Mixed Reality

Multimodal interaction in MR involves combining various input modalities, such as speech, gestures, eye tracking, and haptic feedback, to create a more natural and intuitive interface. Research by [25] emphasizes the need for MR interfaces to support multiple input types to allow users greater flexibility in how they interact with the system. For example, users may use hand gestures to move or resize virtual objects while issuing voice commands to trigger actions.

By incorporating multimodal interaction, MR systems can adapt to user preferences and provide a more immersive experience. Designers must focus on the synchronization of these inputs to avoid confusion and ensure seamless interaction between modalities [25].

## 2.4 Augmented Reality

### 2.4.1 Evolution of AR Development

Augmented Reality (AR) has evolved significantly since its inception in the early 1990s, when the term was first coined by Thomas Caudell, a researcher at Boeing, who developed AR for industrial use. AR integrates virtual content into real-world environments in real-time, enhancing the user’s perception of their surroundings [26]. The Reality-Virtuality Continuum, conceptualized by Milgram and Kishino (1994), illustrates AR as a blend of the real and virtual worlds, distinct from both Virtual Reality (VR), which immerses users in entirely synthetic environments, and Augmented Virtuality, which integrates real elements into predominantly virtual spaces [20].

Over the decades, AR technology has expanded beyond industrial applications into fields such as gaming, healthcare, and education, with the development of various devices like Google Glass and Microsoft's HoloLens [26]. These advancements have positioned AR as a key technology for enhancing human interaction with digital content, driving innovation in industries such as automotive manufacturing, remote healthcare, and tourism.

### 2.4.2 Types of Augmented Reality

There are several types of AR technologies used according to [27], each designed to address specific applications. These include:

* Marker-based AR: This technology uses visual markers, such as QR codes, recognized by a camera, to display relevant virtual content. Marker-based systems are often referred to as "image recognition" technologies.
* Markerless AR: Relying on GPS, accelerometers, and other sensors, markerless AR enables content to be displayed based on the user’s location. It is commonly used in geolocation-based applications like mapping services.
* Projection-based AR: This form of AR projects digital content onto physical surfaces, allowing users to interact with light projections without needing a display device.
* Overlay-based AR: This technology replaces or enhances parts of the real-world view with digital content, requiring object recognition to effectively overlay virtual elements [27].

### 2.4.3 How AR Works

AR operates by creating links between the real world and digital content, triggered by user interactions or through continuous tracking of the user’s environment. The technology can incorporate a variety of interfaces, including 3D objects, images, audio, or video, providing users with a digitally enriched view of their physical surroundings. For example, in medical applications, AR can display 3D anatomical models during surgery, allowing doctors to visualize hidden structures [28].

### 2.4.4 Applications of AR

The applications of AR have broadened considerably. Initially limited to experimental tasks like assembly assistance, AR is now a widely used tool across various sectors:

* Medical Field: AR is employed for remote patient monitoring and diagnosis, where it overlays information on patients in real time. Tools like EyeDecide use AR to project visual simulations of medical conditions [26].
* Education: AR is revolutionizing the learning environment by allowing students to interact with 3D models, such as human anatomy or the solar system, using smartphones or tablets [29].
* Entertainment: Popular games such as Pokémon Go have shown how AR can create immersive gaming experiences by integrating digital characters into real-world environments [30].
* Tourism: AR provides interactive maps and services, enhancing tourist experiences by overlaying information about landmarks and navigation routes [31].

### 2.4.5 Advantages and Challenges

AR offers many advantages, including improved user engagement through immersive experiences and increased efficiency in industries like healthcare and manufacturing. However, AR systems face several challenges, such as the need for high computational power, latency in real-time rendering, and issues related to interoperability between devices and platforms [32].

Moreover, the design of AR applications must ensure contextual sensitivity, meaning that digital content is relevant and adaptive to the user’s environment, which can be computationally demanding. The balance between creating immersive experiences while minimizing user distraction remains a key challenge in AR development [26].

## 2.5 Virtual Reality

### 2.5.1 Definition and Overview

Virtual Reality (VR) refers to the use of immersive technology to simulate interactive, computer-generated environments that give users the sensation of “being there” in a virtual world [34]. Unlike Augmented Reality, which overlays digital elements on the real world, VR completely replaces the real-world sensory input with synthetic stimuli like 3D visuals, spatial audio, and haptic feedback [33]. VR systems often involve hardware such as Head-Mounted Displays (HMDs), haptic gloves, and motion tracking to enhance user immersion [22].

VR was initially developed in the 1960s, with the creation of the Sword of Damocles by Ivan Sutherland, which served as one of the earliest examples of immersive technology [35]. VR has since evolved into a mainstream technology, widely used in gaming, education, healthcare, and other industries. The technology reached new heights in the 2010s with the introduction of consumer-grade headsets like Oculus Rift and HTC Vive, which further popularized VR [36].

### 2.5.2 History of Virtual Reality

VR's history began in the 1960s with pioneering work by Ivan Sutherland, who developed the first HMD. In the following decades, developments such as the CAVE (Cave Automatic Virtual Environment) in the 1990s allowed for more immersive and collaborative VR experiences [37]. Early consumer-focused VR devices like Sega VR and Nintendo’s Virtual Boy in the 1990s failed due to low graphical quality and issues like motion sickness [38].

By the early 2010s, the release of higher-resolution, more affordable VR headsets led to renewed interest in the technology, especially in gaming and industrial training. The release of standalone wireless systems, such as the Oculus Quest, has further contributed to the widespread adoption of VR for both professional and personal use [36].

### 2.5.3 Types of Virtual Reality

Virtual reality can be categorized into two types:

* Immersive VR: This form of VR provides a fully immersive experience where the user is isolated from the real world and engages in a fully simulated environment. Immersive VR systems include HMDs, motion tracking systems, and spatial audio [34].
* Non-immersive VR: Often referred to as desktop VR, this type uses a standard computer screen and is less immersive but still provides an interactive virtual environment [39].

Non-immersive VR lacks the sensory feedback provided by immersive VR systems, and as a result, the feeling of presence is often reduced.

2.5.4 Applications of Virtual Reality

VR has found applications in several sectors beyond gaming, with significant impacts on education, healthcare, retail, and more:

* Education: VR is used to simulate complex environments for training purposes. For example, medical students use VR to practice surgical procedures in a risk-free setting [40]. Companies like Google Expeditions also use VR to create interactive educational experiences across subjects like history and geography [41].
* Healthcare: VR provides surgeons with simulations for practicing delicate operations and helps patients with rehabilitation and exposure therapy for phobias [42].
* Retail: VR enables customers to virtually explore stores and try products before making a purchase, as seen in applications by retailers like Macy's and IKEA [43].
* Training and Development: VR is used for corporate training in high-risk industries, such as safety drills in energy companies like Shell or employee onboarding in retail [37]

### 2.5.5 Advantages and Challenges of Virtual Reality

Advantages:

* Immersion: VR offers a high level of immersion, providing users with a sense of presence in a virtual world [44].
* Training and Education: VR allows for safe, controlled training environments where users can practice complex or hazardous tasks without real-world consequences [40].
* Interactivity: VR offers a unique way for users to interact with digital content, enhancing engagement and retention [44]

Challenges:

* Motion Sickness: Many VR users experience cybersickness due to the discrepancy between visual input and the body’s motion sensors [38].
* Cost: High-quality VR systems require expensive hardware, including HMDs, powerful computers, and motion-tracking systems, which may be prohibitive for some users [37].
* Social Isolation: Due to the immersive nature of VR, users can become isolated from their physical surroundings, making it difficult to integrate VR experiences into collaborative, social environments [45].

## 2.6 Collaborative Mind Mapping in Virtual Reality

With the rise of virtual reality (VR) and the increasing presence of smart devices, the way we interact with technology is undergoing a significant transformation. Traditional interfaces are being enhanced by novel mediums like VR, which enable more immersive and interactive experiences. Collaborative Virtual Environments (CVEs) present new opportunities for real-time collaboration, problem-solving, and brainstorming [46]. Recent research focuses on the use of VR for mind mapping and notetaking, offering novel ways to improve usability, engagement, and cognitive outcomes.

### 2.6.1 Interaction Models in VR for Mind Mapping

The use of VR for mind mapping introduces unique interaction models that differ from traditional 2D applications. Hand gestures are a core interaction technique, allowing users to create and manipulate mind maps in three-dimensional space [47]. This approach leverages embodied interaction, where physical movements like branching or creating links are more intuitive and can reduce cognitive load during complex tasks. Additionally, multimodal inputs, including voice commands and hand controllers, enrich user interaction by offering diverse ways to engage with the system [48]. These methods enable more fluid and dynamic collaboration in virtual spaces, overcoming the spatial limitations of traditional interfaces.

### 2.6.2 Usability and Task Performance in VR-Based Systems

VR systems have demonstrated improvements in usability and task performance compared to traditional mind mapping tools. Studies have shown that users can complete tasks such as branch creation and image handling faster in VR environments than in 2D systems [47]. The immersive nature of VR reduces the time needed for complex operations, making task execution more efficient. Moreover, VR's ability to foster a spatial sense of co-location enhances the collaborative experience, with users reporting greater ease of use and higher satisfaction when compared to standard 2D platforms like Google Docs [48].

### 2.6.3 Cognitive Benefits of Immersive Mind Mapping

The immersive quality of VR plays a significant role in enhancing cognitive processes like memorability and engagement. VR systems, by engaging both spatial awareness and embodied interaction, have been shown to improve task retention and user focus [47]. Users interacting with VR systems report better recall of tasks due to the multisensory experience, which activates different areas of the brain. The physical involvement in the creation of mind maps reinforces memory retention, making VR a promising tool for brainstorming and learning.

### 2.6.4 Enhancing Collaboration and Communication in VR

One of the core advantages of VR-based mind mapping systems is their ability to enhance real-time collaboration. Avatar-based representations of users within the virtual environment contribute to a sense of shared presence, improving communication and teamwork [48]. This enhanced sense of collaboration is a key factor that differentiates VR from traditional tools, enabling users to work more effectively as a team. Real-time updates and changes within the virtual space also promote a high degree of situational awareness, ensuring that all collaborators can keep track of the evolving mind map without disruption.

### 2.6.5 Gamification and Engagement in VR Collaboration

The introduction of gamification into VR mind mapping systems has been shown to further boost user engagement and task efficiency [49]. By incorporating features like real-time performance feedback and collaboration scores, gamified systems incentivize users to collaborate more effectively and complete tasks faster. This increased motivation not only leads to better task completion but also encourages users to adopt more strategic approaches to collaboration. The integration of gamification elements highlights the potential of VR to make mind mapping not just a functional tool, but also an engaging, interactive experience.

### 2.6.6 Challenges and Future Directions

Despite the advantages of VR for collaborative mind mapping, there are still challenges that need to be addressed. Physical discomfort from extended use of VR headsets, inaccuracies in multimodal inputs such as voice recognition, and high hardware costs are some of the limitations currently faced [48]. However, with ongoing advancements in VR hardware and software, these issues are expected to be mitigated. Future developments may focus on improving ergonomics and input precision while also exploring more advanced methods of natural interaction, such as eye-tracking and biometric feedback, to enhance the collaborative experience.

# RESEARCH GOAL

## Problem Statement

While mind-mapping is a valuable tool for enhancing productivity, particularly in academic research, existing 2D mind-mapping applications face limitations such as clutter, spatial constraints, and restricted creativity. Emerging Virtual Reality (VR) mind-mapping applications, such as Noda and Softspace, offer promising alternatives by providing more space and intuitive interactions in a 3D environment. However, these VR apps are still under development and have their own limitations, which raises the question of their effectiveness compared to traditional 2D tools. Additionally, there is a lack of research examining the impact of VR mind-mapping applications on user stress levels, a key factor in determining the usability and productivity of these tools.

## Objective

The objective of this study is to compare the stress levels of users when using a self-developed VR mind-mapping app, MindPool, with similar VR mind-mapping apps like Noda and Softspace, as well as with the traditional 2D mind-mapping app XMind. The study aims to determine whether VR mind-mapping applications can alleviate the limitations of 2D tools while maintaining or improving user productivity and reducing stress.

## Research Question

1. How does user engagement and usability differ between the custom-built VR app, Noda, Softspace, and XMind during mind-mapping tasks, and what factors contribute to sustained engagement and interaction design across these platforms?
2. What effect does the immersive nature of VR mind-mapping (custom-built VR app, Noda, Softspace) have on cognitive overload and mental workload compared to 2D alternatives like XMind, and how does this impact task performance and overall user satisfaction?
3. How does the ability to spatially organize notes in VR (custom-built VR app, Noda, Softspace) influence cognitive load, spatial cognition, and information retention compared to traditional 2D apps (XMind)?
4. How does interaction efficiency in VR-based mind-mapping tools (custom-built VR app, Noda, Softspace) compare with 2D applications like XMind, and how does this efficiency relate to task complexity, user engagement, and task completion times?
5. How do users perceive the trade-off between immersion, task fatigue, and cognitive overload in VR mind-mapping tools compared to 2D apps, and how does this influence user satisfaction and willingness to continue use?
6. What role does task complexity play in mental workload, user engagement, and cognitive overload when comparing the use of VR (custom-built VR app, Noda, Softspace) versus 2D apps (XMind) for mind-mapping tasks?
7. How does the learning curve of using VR-based mind-mapping tools affect cognitive load, usability, and user engagement when compared to more familiar 2D interfaces like XMind?
8. How does collaboration in immersive VR mind-mapping apps (custom-built VR app, Noda, Softspace) influence cognitive overload, flow, and user engagement compared to traditional 2D apps (XMind)?

# METHODOLOGY

## Participants

The study will involve a diverse group of participants, comprising master's students, undergraduate students, and professors. Specifically, the sample will include 5 female graduate students, 5 male graduate students, 10 male undergraduate students, 1 female professor, and 1 male professor. This distribution ensures a balanced representation of academic levels and genders, providing a comprehensive perspective on the effectiveness of mind-mapping applications across different user demographics.

## App Selection

The study will compare the self-developed VR mind-mapping app, MindPool, with two similar VR applications and one traditional 2D app. The selected VR apps are Noda and Softspace, both of which offer immersive mind-mapping experiences with their own unique features and limitations. For the 2D comparison, the widely used mind-mapping application XMind will be included. This selection allows for a comprehensive evaluation of user experiences across both VR and 2D platforms.

## Procedure

The study will begin with pre-study preparation, which includes recruiting a diverse sample of 20 participants (professors, graduate students, and undergraduates) and conducting pre-screening for eligibility. Participants will be informed about study objectives, procedures, and potential risks, and written consent will be obtained. The equipment setup will involve preparing the Biopac Research Ring and setting up the four applications (MindPool, Noda, Softspace, and XMind).

During the orientation session, the study's purpose, objectives, and expected outcomes, along with the mind-mapping tasks, expected actions, and measurements to be recorded will be briefed. Participants will receive an overview of the Biopac Ring and a brief stress-free task will be conducted to establish baseline physiological readings.

For the task execution, participants will complete two tasks: creating a family tree and listing favorite restaurants. Each participant will perform these tasks using all four applications in a randomized order to minimize bias. Participants will be introduced to each application before beginning the tasks, and physiological data (EDA, PPG, ECG) will be collected in real-time to assess stress, cognitive load, and engagement levels. After each task, participants will fill out a short survey on usability, engagement, and task difficulty.

Short rest periods will be included between tasks to reduce carryover effects from fatigue. After completing all tasks, participants will fill out a comparative survey and provide additional feedback through an optional interview or open-ended survey section. Participants will be debriefed on the study's goals and, if requested, receive a summary of their physiological data.

# SYSTEM DESIGN

The purpose of the system design section is to outline the architecture, interaction methods, and functional components of the XR mind mapping application

## **Behavioral Relationships**

### User Interaction Model

The XR mind mapping app is designed to provide users with multiple intuitive interaction methods. Initially, users can interact with the app using handheld controllers or hand gestures, with plans to integrate voice command input in future iterations. These interaction methods are designed to cater to diverse user preferences and ensure a seamless experience.

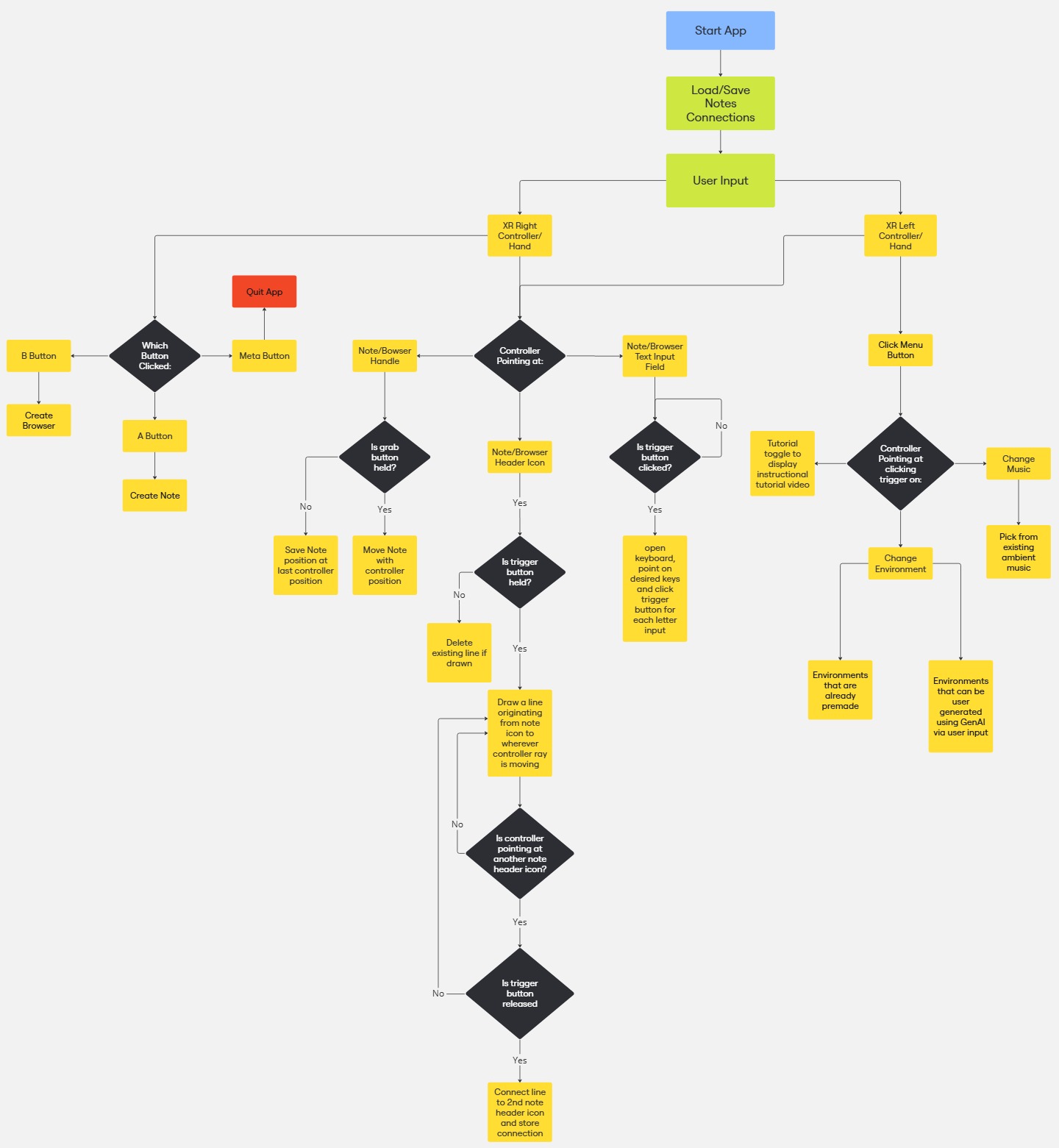
* **Controller-Based Interaction**: Users can point and click to perform actions such as creating nodes, connecting ideas, and typing text.
* **Hand Gestures**: Users can use natural hand movements to manipulate objects in the MR environment.
* **Voice Commands (Future Integration)**: Users will be able to issue verbal commands to perform tasks, further enhancing accessibility and ease of use.

### System Response

The app is designed to respond dynamically to user inputs, providing real-time feedback and ensuring a smooth workflow. Key system responses include:

* **Note Creation**:
  + Users can point anywhere in the XR environment and click to create a new note.
  + A text field will appear, allowing users to input text using a virtual keyboard.
* **Connection Creation**:
  + Users can point at a note, hold the trigger button, and drag it to another node to create connections, forming the basis of the mind map.
* **Text Input**:
  + Users can point at a text field and click to activate a virtual keyboard.
  + Text can be entered by pointing and clicking on the keyboard or by physically poking the keys in the XR environment.
* **Menu Navigation**:
  + Users can click the menu button on the controller to open a persistent menu that follows them throughout the XR environment.
  + The menu includes the following options:
    - **Change Environment**: Users can select from a dropdown menu to switch between different virtual environments or activate passthrough mode to view their physical surroundings.
    - **Change Music**: Users can choose ambient music from a dropdown menu to enhance their mind mapping experience.
    - **Tutorial**: Users can toggle a tutorial video to learn how to use the app effectively.

### Behavioral Flow



### Physiological Signals Integration

To objectively evaluate user experience, physiological signals will be recorded using a Biopac research ring, an external device worn on the participant’s left-hand finger. The device will capture data such as heart rate and skin conductance, which are indicators of stress and engagement. The data will be streamed via Bluetooth to a connected device (e.g., a laptop) running the AcqKnowledge software for real-time monitoring and later analysis. This integration will provide valuable insights into how users respond to the app’s design and interaction methods, enabling a deeper understanding of usability and emotional engagement.

## System Architecture

### Components

1. **Note Component:** Enables users to create notes that also acts as nodes for their mind map.Users can pointanywhere in the XR environment and click to create a new note. Or use hand movements to position notes naturally. Users can also type information into the note using the external virtual keyboard or future voice commands.
2. **Browser Component:** Used for external content retrieval or information integration while mind mapping.
3. **External Virtual Keyboard Component:** Allows users to input text into notes and other text fields.This component is movable and fully interactive within the XR environment. Users can click individual keys using the controller for precise input or physically "poke" keys using hand-tracking for an immersive typing experience. Future voice command input could supplement or replace virtual typing for convenience.
4. **Menu Component:** Provides quick access to app-wide functions and settings. This component is accessible by clicking the menu button on the controller. It is a persistent menu that follows the user throughout the environment.

The following menu options are available for the user:

* **Change Environment:** Switch between virtual environments, generate their own environment or activate passthrough mode to view the physical surroundings.
* **Change Music:** Select ambient music to set the tone for the mind-mapping experience.
* **Tutorial:** Watch a tutorial video for guidance on using the app.

1. **Connections Component:** This component establishes relationships between notes, forming the core structure of mind maps.Users canpoint at a note, hold the trigger, and drag it to another note to establish a connection.

### Technologies Used

The app leverages a combination of modern tools, frameworks, and hardware to achieve its functionality:

1. **Development Tools**:
   * **Unity**: The primary platform for app development, chosen for its robust support for XR applications.
   * **C#**: The programming language used to implement the app’s logic and functionality.
   * **XR Interaction Toolkit 3.0**: A Unity package that simplifies the implementation of VR interactions, such as gesture recognition and object manipulation.
   * **OpenXR**: Ensures compatibility with multiple VR/MR headsets, making the app accessible to a wider audience.
2. **Hardware**:
   * **Meta Quest 3 XR Headset**: Used for testing and deploying the app, providing a high-quality mixed reality experience.
   * **Biopac Research Ring**: A wearable device that captures physiological signals (e.g., heart rate, skin conductance) during the usability study.
3. **Software for Physiological Data**:
   * **AcqKnowledge Software**: Records and processes physiological data streamed from the Biopac research ring, enabling detailed analysis of user stress and engagement levels.

## Design of the VR Application

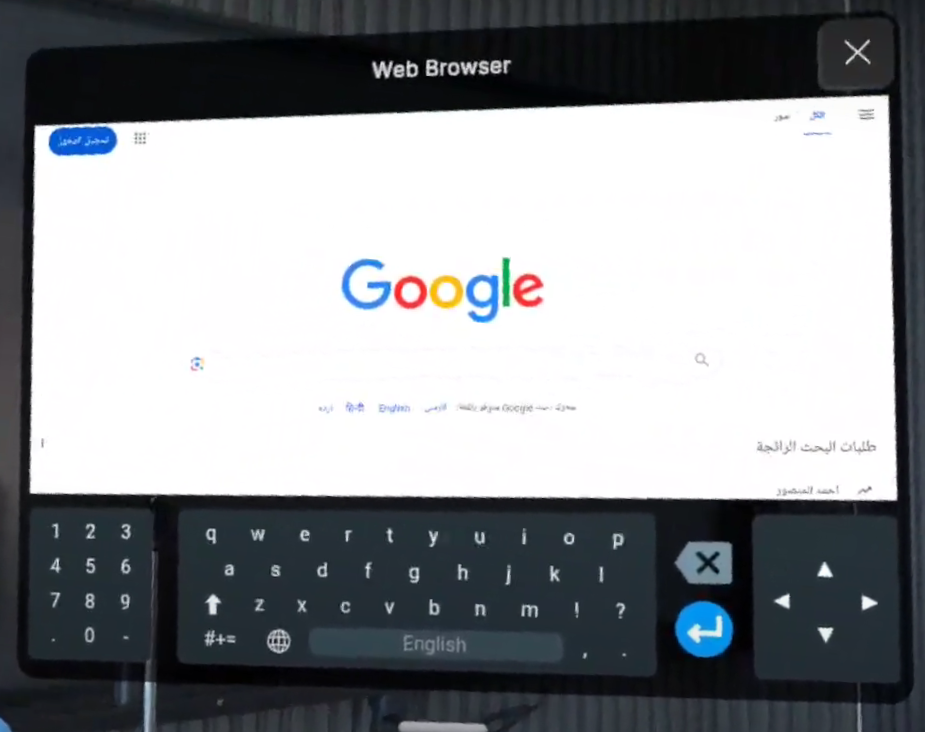
### UI/UX Design

Note:

A blue ball and black text

Description automatically generated

Browser:



External Virtual Keyboard:

A screenshot of a keyboard

Description automatically generated

Menu Panel:

A screenshot of a menu

Description automatically generated

Mind Mapping:

A screenshot of a computer

Description automatically generated

### Environment

Sunrise Environment:

A blue sky with clouds and a sun

Description automatically generated

Night Environment:

A sun shining through clouds

Description automatically generated

Passthrough (Transparent):

A hand reaching out to touch a screen

Description automatically generated

# EVALUATION

## Data Collection

Data collection will include both subjective and physiological measurements. Subjective data will be gathered through pre- and post-usage surveys, with the post-usage survey including the Perceived Stress Scale (PSS) to assess participants' perceived stress levels after using each app. Physiological data will be collected continuously during each session using the Biopac Research Ring, which records Electrodermal Activity (EDA), Photoplethysmography (PPG), body temperature, and Electrocardiography (ECG). This combination of physiological metrics will allow for a comprehensive assessment of stress responses during the interaction with each mind-mapping application.

## Analysis

The data will be analyzed by comparing the average stress levels across the four applications. Statistical analyses, such as Analysis of Variance (ANOVA), will be employed to determine significant differences in both subjective (PSS scores) and physiological (EDA, PPG, temperature, ECG) stress levels across the different apps. Pairwise comparisons will be conducted to identify specific differences between the apps. Correlational analyses will also explore the relationship between subjective stress reports and physiological stress responses. The goal of the analysis is to identify which app(s) are associated with the lowest levels of stress and whether VR-based mind-mapping offers a less stressful experience compared to 2D alternatives.

# TIMELINE

|  |  |
| --- | --- |
| January 31 | IRB Submission |
| April 1 | Completion of Research Study & Experiment |
| April 14 | Final Thesis Draft |
| April 28 | Thesis Defense |

# REFERENCES

1. Kemp, J., Makany, T., & Dror, I. E. (2009). Optimising the use of notetaking as an external cognitive aid for increasing learning. British Journal of Educational Technology, 40(6), 619–635. https://doi.org/10.1111/j.1467-8535.2008.00906.x
2. Fiorella, L., & Kuhlmann, S. (2019). Creating drawings enhances learning by teaching. Journal of Educational Psychology, 112(4), 811–822. https://doi.org/10.1037/edu0000429
3. Farinosi, M., Lim, C., & Roll, J. (2016). Book or screen, pen or keyboard? A cross-cultural sociological analysis of writing and reading habits based on Germany, Italy, and the UK. Telematics and Informatics, 33(2), 410–421. https://doi.org/10.1016/j.tele.2015.09.006
4. Fortunati, L., & Vincent, J. (2014). Sociological insights on the comparison of writing/reading on paper with writing/reading digitally. Telematics and Informatics, 31(1), 39–51. https://doi.org/10.1016/j.tele.2013.02.005
5. Van Meter, P., Yokoi, L., & Pressley, M. (1994). College students' theory of notetaking derived from their perceptions of notetaking. Journal of Educational Psychology, 86(3), 323-338. https://doi.org/10.1037/0022-0663.86.3.323
6. Pauk, W. (1950). How to Study in College. Houghton Mifflin Harcourt Publishing Company.
7. Buzan, T., & Buzan, B. (1996). *The Mind Map Book: Unlock Your Creativity, Boost Your Memory, Change Your Life*. BBC Active.
8. Fry, R. W. (1994). *Improve Your Reading*. Delmar Cengage Learning.
9. Kobayashi, K. (2005). What limits the encoding effect of notetaking? A meta-analytic examination. Contemporary Educational Psychology, 30(2), 242-262. https://doi.org/10.1016/j.cedpsych.2004.10.001
10. Mueller, P. A., & Oppenheimer, D. M. (2014). The pen is mightier than the keyboard: Advantages of longhand over laptop notetaking. Psychological Science, 25(6), 1159-1168. https://doi.org/10.1177/0956797614524581
11. Bui, D. C., Myerson, J., & Hale, S. (2013). Notetaking with computers: Exploring alternative strategies for improved recall. Computers in Human Behavior, 29(6), 2495-2501. <https://doi.org/10.1016/j.chb.2013.06.006>
12. Barak, M., Lipson, A., & Lerman, S. (2006). Wireless laptops as means for promoting active learning in large lecture halls. *Journal of Research on Technology in Education*, 38(3), 245–263. https://doi.org/10.1080/15391523.2006.10782459
13. Kay, R. H., LeSage, A., & Knaack, L. (2009). Exploring student and faculty perceptions of tablet PCs in post-secondary education. *Canadian Journal of Learning and Technology*, 35(1), 1–22.
14. Buzan, T., & Buzan, B. (1996). The Mind Map Book: Unlock Your Creativity, Boost Your Memory, Change Your Life. BBC Active.
15. Eppler, M. J. (2006). A comparison between concept maps, mind maps, conceptual diagrams, and visual metaphors as complementary tools for knowledge construction and sharing. *Information Visualization*, 5(3), 202-210. <https://doi.org/10.1057/palgrave.ivs.9500131>
16. Nesbit, J. C., & Adesope, O. O. (2006). Learning with concept and knowledge maps: A meta-analysis. *Review of Educational Research*, 76(3), 413-448. <https://doi.org/10.3102/00346543076003413>
17. Al-Jarf, R. (2009). Enhancing freshman students' writing skills with a mind mapping software. *Journal of Faculty of Education and Sciences*, 7(2), 150-162.
18. Wang, J., Wang, X., Lu, J., & Xu, Z. (2022). Investigating the User Experience of Mind Map Software: A Comparative Study based on Eye Tracking. *International Journal of Advanced Computer Science and Applications*, 13(11).
19. Davies, M. (2011). Concept mapping, mind mapping and argument mapping: What are the differences and do they matter? *Higher Education*, 62(3), 279-301. <https://doi.org/10.1007/s10734-010-9387-6>
20. Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems*, 77(12), 1321-1329.
21. Speicher, M., Hall, B. D., & Nebeling, M. (2019). What is mixed reality? *Extended Reality in UX: Immersive and Engaging User Experiences*, 1-22. <https://doi.org/10.1145/3290605>
22. Jerald, J. (2015). *The VR Book: Human-Centered Design for Virtual Reality*. Morgan & Claypool Publishers. <https://doi.org/10.1145/2792790>
23. Benyon, D., Quigley, A., O'Keefe, B., & Riva, G. (2014). Presence and digital tourism. *AI & Society*, 29(4), 521-529. <https://doi.org/10.1007/s00146-013-0517-8>
24. Billinghurst, M., Clark, A., & Lee, G. (2015). A survey of augmented reality. *Foundations and Trends in Human-Computer Interaction*, 8(2-3), 73-272. <https://doi.org/10.1561/1100000049>
25. Turk, M. (2014). Multimodal interaction: A review. *Pattern Recognition Letters*, 36, 189-195. <https://doi.org/10.1016/j.patrec.2013.07.003>
26. Arena, F., Collotta, M., Pau, G., & Termine, F. (2022). An Overview of Augmented Reality. *Computers*, 11(28). <https://doi.org/10.3390/computers11020028>
27. Schmalstieg, D., & Hollerer, T. (2016). *Augmented Reality: Principles and Practices*. Addison-Wesley.
28. Hu, F., Xie, D., & Shen, S. (2013). On the application of the internet of things in the field of medical and health care. *IEEE Green Computing and Communications*, 2053-2058.
29. Lavrentieva, O. O., Arkhypov, I. O., Krupskyi, O. P., Velykodnyi, D. O., & Filatov, S. V. (2020). Methodology of using mobile apps with augmented reality in students’ vocational preparation process. *Proceedings of the 3rd International Workshop on Augmented Reality in Education*.
30. Noreikis, M., Savela, N., Kaakinen, M., Xiao, Y., & Oksanen, A. (2019). Effects of Gamified Augmented Reality in Public Spaces. *IEEE Access*, 7, 148108–148118.
31. Tom Dieck, M. C., Jung, T., & Han, D. I. (2016). Mapping requirements for the wearable smart glasses augmented reality museum application. *Journal of Hospitality and Tourism Technology*, 7(3), 230-253.
32. Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems, and applications. *Multimedia Tools and Applications*, 51(1), 341-377.
33. Brooks, F. P. (1999). What’s real about virtual reality? *IEEE Computer Graphics and Applications*, 19(6), 16-27.
34. Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication*, 42(4), 73-93.
35. Sutherland, I. E. (1965). The ultimate display. In *Proceedings of IFIP Congress*, 506-508.
36. Sherman, W. R., & Craig, A. B. (2019). *Understanding Virtual Reality: Interface, Application, and Design* (2nd ed.). Morgan Kaufmann.
37. Cruz-Neira, C., Sandin, D. J., & DeFanti, T. A. (1993). Surround-screen projection-based virtual reality: The design and implementation of the CAVE. *ACM SIGGRAPH Computer Graphics*, 27(2), 135-142.
38. Rebenitsch, L. (2015). Managing cybersickness in virtual reality. *XRDS Crossroads*, 22(1), 46-51
39. Suh, K.-S., & Lee, Y. E. (2005). The effects of virtual reality on consumer learning: An empirical investigation. *MIS Quarterly*, 29(4), 673-697.
40. Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. In *Proceedings of eLearning and Software for Education Conference*.
41. Brown, A., & Green, T. (2016). Virtual reality: Low-cost tools and resources for the classroom. *TechTrends*, 60(5), 517–519.
42. Garcia-Palacios, A., Hoffman, H., Carlin, A., Furness, T. A., & Botella, C. (2002). Virtual reality in the treatment of spider phobia: A controlled study. *Behavior Research and Therapy*, 40(9), 983-993.
43. Flavián, C., Ibáñez-Sánchez, S., & Orús, C. (2019). The impact of virtual, augmented, and mixed reality technologies on the customer experience. *Journal of Business Research*, 100, 547-560.
44. Sanchez-Vives, M. V., & Slater, M. (2005). From presence to consciousness through virtual reality. *Nature Reviews Neuroscience*, 6(4), 332-339.
45. Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence*, 6(6), 603-616.
46. Benford, S., Greenhalgh, C., Reynard, G., Brown, C., & Koleva, B. (2001). Understanding and constructing shared spaces with mixed-reality boundaries. *ACM Transactions on Computer-Human Interaction*, 8(2), 185-223.
47. Miyasugi, H., Kuroki, T., & Inoue, H. (2017). Implementation and evaluation of a multi-user mind map authoring system using virtual reality and hand gestures. *Proceedings of the 2017 IEEE Symposium on 3D User Interfaces*, 181-190.
48. Kut’ák, Z., Novotný, P., & Martinák, M. (2019). An interactive and multimodal virtual mind map for future workplaces. *International Journal of Advanced Computer Science and Applications*, 10(3), 235-245.
49. Yang, L., Zhao, X., & Liu, Y. (2024). Putting our minds together: Iterative exploration for collaborative mind mapping. *Journal of Virtual Reality and Immersive Environments*, 15(1), 41-55.