Breaking Virtual Barriers: Investigating Virtual Reality for Enhanced Educational Engagement

Robert Sims, B.Sc (Hons)

School of Computing and Communications

Lancaster University

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Declaration

I declare that the work presented in this thesis is, to the best of my knowledge and belief, original and my own work. The work presented in this thesis was completed under the guidance of Dr. Abhijit Karnik at Lancaster University's School of Computing and Communications. The material has not been submitted, either in whole or in part, for a degree at this, or any other university. This thesis does not exceed the maximum permitted word length of 80,000 words including appendices and footnotes but excluding the bibliography. A rough estimate of the word count is: 54647.

Robert Sims

Abstract

Virtual reality (VR) is an innovative technology that has regained popularity in recent years. In the field of education, VR has been introduced as a tool to enhance learning experiences. This thesis presents an exploration of how VR is used from the context of educators and learners. The research employed a mixed-methods approach, including surveying and interviewing educators, and conducting empirical studies to examine engagement, usability, and user behaviour within VR.

The results revealed educators are interested in using VR for a wide range of scenarios, including thought exercises, virtual field trips, and simulations. However, they face several barriers to incorporating VR into their practice, such as cost, lack of training, and technical challenges.

A subsequent study found that virtual reality can no longer be assumed to be more engaging than desktop equivalents. This empirical study showed that engagement levels were similar in both VR and non-VR environments, suggesting that the novelty effect of VR may be less pronounced than previously assumed.

A study against a VR mind mapping artifact, VERITAS, demonstrated that complex interactions are possible on low-cost VR devices, making VR accessible to educators and students. The analysis of user behaviour within this VR artifact showed that quantifiable strategies emerge, contributing to the understanding of how to design for collaborative VR experiences.

This thesis provides insights into how the end-users in the education space perceive and use VR. The findings suggest that while educators are interested in using VR, they face barriers to adoption. The research highlights the need to design VR experiences, with understanding of existing pedagogy, that are engaging with careful thought applied to complex interactions, particularly for collaborative experiences. This research contributes to the understanding of the potential of VR in education and provides recommendations for educators and designers to enhance learning experiences using VR.

Contributing publications

Sims, R. et al. 2021. Logibot: Investigating Engagement and Development of Computational Thinking Through Virtual Reality. *2021 7th International Conference of the Immersive Learning Research Network (iLRN)* (May 2021), 1–5. DOI: 10.23919/iLRN52045.2021.9459352.

Sims, R. and Karnik, A. 2021. VERITAS: Mind mapping in Virtual Reality. *2021 7th International Conference of the Immersive Learning Research Network (iLRN)* (May 2021), 1–8. DOI: 10.23919/iLRN52045.2021.9459348.

Sims, R. et al. 2022. Step Into My Mind Palace: Exploration of a Collaborative Paragogy Tool in VR. *2022 8th International Conference of the Immersive Learning Research Network (iLRN)* (May 2022), 1–8. DOI: 10.23919/iLRN55037.2022.9815936.

Sims, R. and Karnik, A. 2022. Opportunities and Challenges for VR-Mediated Educational Resources: An Educators Perspective. *EDULEARN22* (Jul. 2022), 8810–8819. DOI: 10.21125/edulearn.2022.2109.

Sims, R. and Karnik, A. 2023. Investigating the emergence of strategy in VR based reflective tasks. *Annual Scholarship Review 2023 (Blackpool and The Fylde College*), for[1]thcoming.

[1] Logibot: Investigating Engagement and Development of Computational Thinking Through Virtual Reality was conducted in concert with SCC.402 Masters Students at Lnacaster University as part of their coursework. The author of this thesis major contributions were study design, literature review and results analysis. The author also wrote the study up for publication. Appropriate attributions for this published paper have been made.

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Chapter 1

Introduction

1.1 Problem Statement

It has long been recognised that VR (Virtual Reality) has the potential to significantly impact education and specifically student's engagement in the learning process [177, 185, 203]; however, barriers in the form of complex setups requiring connection to a powerful PC and the overall cost of the equipment have prevented widespread adoption of the technology, which has also resulted in a lack of educational applications being produced for VR devices. Recent advances in VR technology have made low-cost untethered VR headsets accessible to the public. Devices such as the Oculus Go and Meta Quest are untethered and consequently more manageable in a traditional classroom environment. These devices open up the intriguing possibility of being included by educational institutions in their flipped learning strategy [154].

Beyond the novelty factor of VR headsets, for education it is essential to understand the exact use cases that benefit the learning process. Historically and commercially, these devices are geared toward content consumption rather than content creation. Educational institutions commonly use them as exploration devices, such as viewing 360-degree videos of interesting places on earth, visualising chemical structures, or viewing parts of the galaxy. These activities are typically passive in nature, with limited interactivity and as such address only the lower cognitive processes, such as those illustrated in Blooms Taxonomy [24], of remembering and understanding. Within education, and computing specifically, there is an opportunity to develop and leverage VR to improve student engagement in computational thinking, logic and programming tasks. Attempts are already well underway to move programming to a more visual based medium and are ripe for transition to VR environments. Scratch, developed by the Massachusetts Institute of Technology (MIT) [152], is a software program designed to introduce and expose primary level students to computational concepts, such as events, variables and operators. Microsoft's Visual Programming Language (VPL) extends this early exposure into a fully-fledged programming environment. Its concept was to assist programming novices in creating programs but has since evolved as a rapid prototyping toolset used by experienced programmers. Both of these programs and their design philosophies seem ideal candidates for translating to VR.

A barrier to VR adoption in education, or indeed any interactive tool, is the challenges presented in creating content for such devices. Platforms such as Moodle and Canvas have gone some way to mitigate these issues by providing effective tools and frameworks to store, organise, manage, and distribute course content to students. There is opportunity to explore similar or new concepts to make VR applications more manageable content wise for both teachers and students.

The importance of this topic is illustrated by its relevance to students and recommendations of government agencies in respect of technology. With students growing up with technology they are comfortable with they expect the use of technology to support their learning. The next logical step in this incorporation of technology within education is VR, especially considering the recommendations of the 2015 FELTAG (Further Education and Learning Technology Action Group) report [61] to incorporate technology to improve the learner's experience.

1.2 Research Questions

The main aim of this thesis is to identify appropriate use case for VR in education beyond the classic topic specific uses (i.e., medical procedures, learning an engineering process etc). To achieve this, educators' attitudes towards VR was first explored, both from a use case basis and from a usability perspective of the educator and use the results of this initial exploration to narrow the research area and inform subsequent studies. In this context, there was a need to consider the development and improvement of Virtual Reality (VR) as a transformative medium in computing education, including bolstering computational thinking. VR's immersive nature offers a novel approach to engage students more deeply with the subject matter. By transcending the conventional classroom boundaries, VR facilitates an interactive and experiential learning environment. This environment is particularly conducive to grasping intricate computer science concepts, allowing students to visualise and manipulate abstract computational structures in a more tangible way. The aim is to leverage VR to make education, including in computing, not only more accessible but also more effective, aligning with the contemporary needs of the educational sector.

Therefore, the purpose of this thesis is to explore the potential of VR in redefining the pedagogical strategies employed in education. The focus is on how VR can be harnessed to provide a more hands-on, engaging, and comprehensive learning experience including computational thinking and topic agnostic learning. By integrating VR into education, this thesis seeks to address the gaps in traditional teaching methods from an educators' perspective. This aligns with the broader goal of preparing students for the increasing demands of the technology-driven future, ensuring they are not only well-versed in theoretical concepts but also proficient in practical problem-solving skills. The main challenge faced in this research is the balance between issues relevant to the field of HCI and those in education. VR may be effective on an application level, but its use within education has to show 'learning taking place'. While the research sits firmly in the HCI and computing domain, due regard must be given to existing and upcoming pedagogy on how technology might be used to improve learning. Ultimately, this thesis proposes two specific questions with respect to VR being used within an educational and computing environment. The two research questions proposed are:

RQ1: *Can low-cost VR devices support engaging activities that target higher order cognitive processes within a multi-user, collaborative educational setting*?

The context for this question is that VR offers tangible benefits over existing learning activities within the Technology Enhanced Learning space. Domain specific learning activities in VR such as medical procedures [73, 95] offers replicable and safe learning. Learning in VR has been shown to increase attention [177] and motivation [86]. While there are plenty of domain specific examples, there remains a gap in the literature that focuses on learning activities within VR that are domain agnostic. Similarly, low-cost devices are not represented well. this thesis addresses these particular issues by investigating the following sub-research questions: -

- RQ1.1 *What specific and existing interaction paradigms and methods can be utilised to create engaging and interactive educational VR experiences?*
  There is a plethora of research on VR interaction methods. The challenge is to identify the ones best suited to a specific scenario. This thesis especially looks at this through an educational and low-cost device lens.

- RQ1.2 *Can VR be used for domain agnostic learning.?*
  Domain agnosticism in educational VR is useful for broadening the scope of learning beyond topic-specific applications, which currently dominate the field. By focusing on domain-agnostic VR activities, this thesis can address the gap in understanding and application of VR in a more versatile manner. This approach is not just about diversifying content, but also about delving into the pedagogy behind various types of learning and integrating these insights into domain-agnostic VR experiences. Such a strategy enhances VR's applicability across different subject areas, fostering universally valuable skills such as critical thinking and creativity. It also allows for foundational research in pedagogy, isolating VR's educational impact from specific subject matter and developing adaptable teaching strategies. Furthermore, domain-agnostic VR is inclusive, engaging a diverse range of learners, and scalable, making it a cost-effective option for educational institutions. By shifting focus from subject-specific to domain-agnostic VR applications, this thesis can uncover new ways to leverage VR as a transformative educational tool, breaking traditional subject boundaries and enhancing learning experiences across various disciplines.

The educational VR field is well represented by topic specific activities and applications; however, domain agnostic activities and applications are less well understood. We look to address this by first looking at the pedagogy behind certain types of learning and how this can be incorporated into domain agnostic learning experiences.

- RQ1.3 *How do users' cognitive behaviours manifest when building mind maps within a VR mind mapping application?*
  This question is structured to investigate individual cognitive processes within the context of a VR mind mapping environment. It opens up avenues for exploring how VR technology impacts and possibly enhances the mind mapping process, looking into aspects such as user engagement, interaction patterns, and the effectiveness of VR in facilitating mind mapping activities compared to traditional methods.

RQ2: W*hat are the key factors in creating, organising, and delivering VR content in education?*

Considerable research has been conducted to determine the benefits to students for VR based learning, however an educator's perspective, especially around barriers presented, is often overlooked. This thesis breaks down RQ2 into three sub-questions as follows:

- RQ2.1 *What do educators want to use VR for in their pedagogy?*
  This is key in determining where to target development effort, especially around domain agnostic learning.

- RQ2.2 *What barriers exist to educators wanting to implement VR within their learning environments?*
  This thesis investigates several factors that might present as barriers to using VR for education, such as time, platforms, institution derived barriers and understanding of VR itself by educators.

- RQ2.3 *What tools or processes need to exist to enable effective use of VR by educators?*

This thesis explores whether existing tools and processes are suitable to create and curate educational VR content or if new ones might be required.

1.3 Research Methodology

1.4 Contributions

This thesis advances the understanding of VR use within education in the context of domain agnostic learning activities and how educators can be included in the application of these. In particular, the main contributions are as follows: -

- The validation of useful and implementable interaction methods for reflective learning activities on low-cost VR devices (RQ1.1). This thesis purposefully restricts the initial artifact, VERITAS, to operating on the Oculus Go VR device, the lowest cost mainstream VR device available at the start of this thesis/study period. A series of established and well documented interaction methods is utilised, and a user study is conducted to assess the effectiveness of these methods within a mind mapping activity. The conclusion of this study defines a base line level of interactions that can be easily ported to more complete 6DoF devices that have since become available and supplanted the 3DoF devices.

- Demonstration that VR no longer guarantees higher engagement compared to tradition Technology Enhanced Learning activities (RQ1.2). Through the LogiBot study, it is identified that familiarity with VR among learners has negated the assumed improved engagement commonly ascribed to learning activities within VR. This reiterates the need to think carefully and pedagogically about the types of learning activities that can take place within VR. This led us, in tandem with educators' ideas about how to use VR, to explore inquiry-based learning and topic agnostic learning activities for implementation within VR.

- The identification of two quantifiable and distinct user behaviours exhibited when undertaking a mind mapping exercise in VR (RQ1.3). In the first VERITAS study, two distinct strategies are observed in how users constructed a mind map – *sequential* and *grouping*. This has implications when considering how to design and implement fully featured, enjoyable and useful mind-mapping applications in VR.

- Understanding how educators perceive and want to use VR within their pedagogy (RQ2). A user perception study explores what educators want to use VR for (RQ2.1) and what the current barriers, both practically and technologically, that they are concerned about or prevents them implementing VR learning activities (RQ2.2). As a result of this investigation, recommendations are provided to account for their preferences and to address these barriers (RQ2.3).

1.5 Thesis Structure

The thesis structure is as follows:

Chapter 2 presents a literature review, focusing on the intersection of VR and education. It aims to explore the evolving role of VR in educational settings, delineating its potential to transform learning experiences. The review extends into identifying and analysing the barriers that currently impede the integration of VR in educational contexts. Furthermore, it delves into the concept of topic agnostic learning within VR environments, examining how VR can support diverse learning subjects beyond specific disciplinary confines. This analysis not only highlights the current state of VR in education but also sheds light on future pathways and potential developments in this growing field.

Chapter 3 explores the existing literature and begins by discussing how Technology Enhanced Learning (TEL) contributes to promoting engagement and interactivity from learning with educational activities. The chapter describes the educational landscape with respect to technology and introduce relevant pedagogical concepts. The chapter explores how reflective tasks and inquiry-based learning exist within this domain and how specific activities such as mind mapping can utilise and foster these approaches. An overview of current virtual reality use within education is given with reference to strength, weaknesses and barriers to adoption highlight. Finally, the chapter looks existing virtual reality paradigms and examine good practice within the field.

Chapter 4 details a study investigating educators' perception of VR use, anticipated and preferred use cases and barriers to adoption. The study aims to fill a research gap concerning the creation, re-use and modification of educational resources for VR. This study surveyed 61 educators across the full spectrum of education and additionally included five in depth semi-structured interviews to elicit further detailed responses in addition to the survey. As an exploratory study into a new area, this research is intended to provide a baseline understanding of the issues facing educators for these specific factors, thus informing future research and design of VR educational applications and platforms.

Chapter 5 introduces LogiBot, an artifact aiming to teach programming concepts and logical thinking trough an interactive VR application. It leverages the concept of pseudo physical interactions with tangible objects within VR as a way of promoting engagement. The study compares LogiBot against an existing, similar desktop PC based application, LightBot. The study attempts to determine if there is any measurable or perceived benefit in terms of engagement within VR as opposed to existing or traditional platforms.

Chapter 6 and Chapter 7 detail a two-part study. Chapter 5 looks at whether low-cost VR devices can support complex interactions required for activities such as mind mapping. A survey of applicable interaction paradigms and methods is conducted then suitable methods are applied within a new artifact, Veritas, a mind mapping application operating on the Oculus Go VR device. This first phase consists of a user experience study with quantitative and qualitative metrics analysed. The second part (Chapter 6) consists of a user behaviour study conducted against the same artifact. This study looks to see if distinct behaviours emerge during the mind mapping activity. This is done through the lens of trying to understand how users behave in such an activity so that design recommendations can be made with a view to creating a collaborative version of the artifact.

Chapter 8 discusses how the studies within the thesis answer the research questions. It identifies a set of guidelines and recommendations for the continued development of interactive, VR based reflective activities such as mind mapping especially with a view to leveraging collaboration and paragogy. It identifies methods and techniques to promote collaboration and effective communication within VR. This section also summarises educators' perspective on VR and its educational use with application areas defined and use case scenarios detailed. Finally, it identifies limitations and areas for future work.

Chapter 9 concludes the thesis.

Chapter 2

Methodology

2.1 Overview

As the existing literature has revealed a lack of comprehensive understanding of using VR within education, particularly in relation to the challenges that educators face, exploratory research approach is utilised to learn more about the subject, explore ideas, and identify potential areas for future research. Data collection techniques used in exploratory research frequently include interviews, observations, focus groups, case studies, and surveys. Qualitative, quantitative, or a combination of both types of data may be gathered during exploratory research. In order to form an overall picture, a mixed-method research design was chosen that combined quantitative and qualitative research techniques for each of the distinct studies in this thesis. By using quantitative and qualitative data, these empirical studies complemented the overall exploratory nature of the research was used to address the research questions. Together, exploratory research and empirical studies provided a comprehensive understanding of the research problem. This exploratory research was also used to clarify and modify the research questions throughout the course of this thesis. In combining these approaches, a more complete understanding of the topic was gained, and the combination of quantitative and qualitative data provided complementary insights into the research problem, thereby increasing the validity and reliability of the findings.

The initial research investigated educators' perceptions of VR, their anticipated use case and any potential barriers for the adoption of VR by those educators within their practice. The purpose of this initial research was to examine the barriers to and facilitators of VR adoption in the classroom, with a focus on the provision of relevant educational resources. The benefits to pupils have been thoroughly explored by earlier studies, therefore the thesis instead concentrates on how educators view the practicality of VR. The focus was on developing, repurposing, and adapting instructional materials for VR experiences because this is an area where the existing literature is lacking. Educators were surveyed and interviewed to learn their thoughts on these issues and find out what kinds of things they plan to do with VR. This study aimed to lay the groundwork for future study and creation of VR educational applications and platforms by providing a basic understanding of the challenges faced by educators in regard to these specific elements.

The output of the above informed the next two pieces of research. The first open question was around the validity of assuming that VR is more engaging than desktop educational applications. Another question was looking at how VR could be used to develop computational thinking in students. The similarities and differences were evaluated between two block-based programming learning games, LightBot and the designed and built similar VR application - LogiBot. LightBot's gamification method used a condensed form of the visual block-based interaction style used by tools like Scratch to teach programming fundamentals. The justification for this stems from the idea of computational thinking, which advocates for the isolation of syntax from logic. This chapter postulated that VR would be more engaging than traditional desktop education software. It was considered that anticipated increased engagement can be linked to the rich opportunities for interaction with pseudo physical props and environments present in VR games.

The third piece of research looked at one of the elements output in the educators perception study – that educators would like to use VR for thought exercises. For this, a user experience study was run against a developed application that sought to identify relevant interaction techniques that can support reflective tasks with VR, specifically mind mapping, on low-cost VR devices and their limited input methods. It is common in HCI to attempt to solve challenges presented in interaction to invent or create custom hardware to solve those challenges. This research deliberately restricts itself to existing hardware in order to explore what is possible without resorting to additional hardware, which would add a burdensome level of complexity to any implementation and would thus make it unattractive to educational institutions.

Finally, the output of the above research informed the final piece of research. Behaviours of users within the VERITS artifact was subsequently explored to see if conducting mind mapping in 3D space offers any advantages over a traditional 2D implementation. The purpose of this piece of research was to analyse the resulting patterns of student behaviour and approach to learning in a VR mind mapping environment. This final chapter sought to know how users interact with the task of mind mapping, and specifically any behaviours, in order to create design guidelines for a collaborative version of the application.

All research used a mixed method approach adopting both qualitative and quantitative data to answer the research questions. A mixed method approach is common in the HCI fields and allows for the seeking of user feedback which can be triangulated with quantitative data to find meaning in quantitative data.

2.2 Combined Methodology Summary

All four chapters share a commitment to mixed-methods research, which incorporates both quantitative and qualitative forms of data to offer a comprehensive perspective on the issues under study. This methodological framework allows for the nuanced exploration of various aspects of virtual reality (VR) in educational settings.

2.2.1 Data Collection and Variables

Chapter 4 relies heavily on interviews and Qualtrics surveys to gather data. The focus is primarily on the perceptions and experiences of educators in the context of educational technology. The variables examined include attitudes, level of use, and perceived benefits or drawbacks of educational technology.

Chapter 5 builds on this foundation by introducing gameplay elements. Specifically, participants are asked to solve tasks in LogiBot and LightBot, two VR educational games. The study hypothesises about the increased levels of engagement and interactivity offered by VR. Variables of interest include task completion time, level of engagement, and accuracy of solutions.

Chapter 6 maintains the focus on VR but transitions to a specific tool named VERITAS designed for mind mapping. While it retains the mixed-methods approach, it dives deeper into the realm of usability and learnability. Variables here expand to include ease of use and user satisfaction, adding an additional layer of complexity to the research.

Chapter 7 focuses on user behaviour within the VERITAS tool, recording interactions and applying thematic analysis to observed behaviours. Quantitative variables like task completion time and precision are juxtaposed with qualitative variables such as observed and nonverbal behaviour.

2.2.2 Contributions to Subsequent Research

Chapter 4 'Opportunities and Challenges for VR within Education', embarks on a detailed exploration the conceptualisation of VR resources and world building, educational benefits, engagement, educators' perception, and multi-modal learning in VR. The primary aim of this chapter is to serve as a foundational layer, exploring the wider theme of technology in education. This sets the stage for a more focused inquiry into VR, which is undertaken in chapter 5, employing questionnaires and interviews of current educators. The findings and insights gleaned here are pivotal, as they lay the groundwork for the subsequent investigations in Chapter 5.

Building on this foundation, Chapter 5 'LOGIBOT: Engagement Through Virtual Reality', details an artifact designed to teach programming concepts and logical thinking through an interactive VR application. This chapter explores the use of pseudo-physical interactions with tangible objects in VR to promote engagement and compares LogiBot with a similar desktop PC-based application, LightBot, to determine any measurable or perceived benefits in terms of engagement within VR compared to traditional platforms. This chapter is designed to extend and elaborate on the findings of Chapter 4, with an objective to evaluate the effectiveness of the LogiBot VR application in promoting engagement and developing computational thinking skills, using a mixed-methods approach that includes both quantitative and qualitative measures for data collection and analysis. The methodology adopted in Chapter is intricately linked to and informed by the outcomes of Chapter 4, ensuring a cohesive and comprehensive narrative. While Chapter 4 focuses on leveraging VR to teach programming concepts and logical thinking through an interactive and compare its effectiveness against traditional platforms, Chapter 5 extends this exploration by examining whether low-cost VR devices can support complex interactions for activities like mind mapping, which involves surveying interaction paradigms and methods applicable to VR. Both chapters collectively contribute to understanding the effectiveness and applicability of VR in educational contexts, particularly in terms of engagement and the capability of VR technology to facilitate complex educational interactions.

Chapter 6 builds upon the previous papers by providing depth in the form of a specific application—VERITAS. It also broadens the inquiry by introducing the concept of paragogy or peer-based learning. By focusing on usability, it serves as a natural segue into Chapter 7.

Chapter 7 complements and completes the research arc by taking the usability and learnability questions of chapter 6 and further dissecting them through a thematic analysis of user behaviour. It offers a granular understanding of how users interact with educational VR tools, bringing the research full circle.

In summary, each paper successively builds upon the work of the previous papers, starting from a broad inquiry into technology in education and funnelling down to a detailed exploration of specific aspects of VR for educational purposes. This forms a cohesive research narrative that is both broad in scope and deep in focus.

2.2.3 Methodology Comparison by Chapter

Table 1 Methodology Comparison

Criteria	Chapter 4	Chapter 5	Chapter 6	Chapter 7
Data Collection	Semi structured interviews and researcher created survey (Qualtrics)	Quantitatitve analysis of gameplay in LightBot and LogiBot and Qualitative (thoughts and experiences) through	Quantitative data on task completion times, error rates and accuracy. Qualitive surveys for simulator sickness and usability	Observations of user behaviour within VERITAS resulting in quantitative and qualitative data. Re-analysis of data

Criteria	Chapter 4	Chapter 5	Chapter 6	Chapter 7
		a survey (user engagement survey) and semi structured interviews.	survey (User Experience questionnaire)	collected in chapter 6 through a different lens.
Participant Selection	Educators using technology. Participant recruitment though researchers existing professional network and Discord channels.	Participants over 18 years of age were recruited from current students and alumni of Lancaster University through email invitation.	Participants over 18 years of age were selected from Lancaster University and Blackpool and the Fylde College by way of an open email invitation. Participants did not require prior experience of virtual reality and there were no stipulated exclusions criteria that would prevent potential participants taking part in the study.	As per chapter 6.
Sample Size	61 survey respondents, 5 interviewees	10 participants	24 participants	24 participants
Study type	Mixed methods	Mixed methods	Mixed methods	Mixed methods
Analysis Tools	Qualtrics, Excel, IBM SPSS 26	Excel and IBM SPSS 26	Excel, inbuilt Excel file provided with the User Experience Questionnaire and IBM SPSS 26	Interview transcription through Otter.ai, thematic Analysis through Atlas.ti, Excel, inbuilt Excel file provided with the User Experience Questionnaire and IBM SPSS 26

Criteria	Chapter 4	Chapter 5	Chapter 6	Chapter 7
Variables Measured	Demographics, teaching experience, subjects, teaching level, attitudes to resources creation, opinions on the use of VR in education. For and exhaustive list of questions asked please see appendix B.1	Questionnaire (user engagement survey – see appendix B2), user behaviour and free form interview responses (attitudes towards the application) via semi-structured interviews.	Controller interactions, tile metrics (movement, rotation, size), task completion times, questionnaires (simulator sickness questionnaire and user experience questionnaire – see appendix B3 and B4),	As per chapter 6 plus observed behaviour (first link / group creation times) within the application.
Pilot Study	To ensure the relevance and appropriateness of the interview questions, a pilot study was conducted. This helped in refining the questions and making them more suitable for the research objectives.	Yes – ensured the core functionality existed for a usable application.	Yes – ensured the core functionality existed for a usable application.	As per chapter 6
Triangulation	To validate and enhance the trustworthiness of the results, the data obtained from semi-structured interviews were triangulated with data collected from other methods, such as surveys and document analysis.	Limited triangulation, main through associating and interpreting the User Engagement Surveys against interview response and researcher observations.	To validate and ensure the trustworthiness of the results, the data acquired through semi-structured interviews was triangulated with data collected via other approaches, such as surveys and document analysis. This cross-checking of data from different sources helps to confirm findings and reduce the impact of any single source's biases.	Triangulation formed the essence of this study through observation and thematic analysis of user behaviours resulting in the identification distinct strategies in building mind maps.

Criteria	Chapter 4	Chapter 5	Chapter 6	Chapter 7
Bias Mitigation	Acknowledgment of the possibility of biases like researcher's own bias, which may influence the direction of the discussion, and social desirability bias, where participants might provide answers they think are expected rather than genuine ones. The interviewers underwent appropriate training and practiced exercises to develop their expertise in qualitative research methodologies. This training included developing the ability to build rapport with participants, which is crucial for obtaining genuine and unbiased responses. Triangulation helps in cross-verifying the data and reducing the impact of any single source of bias.	Bias was mitigated through a mixed-methods approach, integrating both quantitative (task completion time and accuracy) and qualitative (questionnaires and interviews) data. This strategy provided an understanding of LOGIBOT's effectiveness in VR education by balancing objective metrics with subjective user experiences.	The main primary data collection method, the User Experience Questionnaire, includes several bias mitigation strategies . This includes using neutral wording to avoid leading responses, providing diverse response options like Likert scales for nuanced feedback, and ensuring anonymity and confidentiality to encourage honesty. Additionally, clear and concise questions grouped by topics prevents confusion and mixed responses, thus gathering more accurate and unbiased data.	As per chapter 6 plus utilising more than one coder to analyse the videos. This helped mitigate individual biases. A detailed and standardised coding scheme with well-defined categories reduced ambiguity and subjective interpretation. Regular meetings between coders discussed and aligned their coding decisions which helped maintain consistency and address any emerging biases.
Reliability Measures	Inter-coder reliability was used to identify the level of agreement between different coders> This was used to identify and correct inconsistencies.	The primary data collection method in the study, the User Engagement Survey, used reliability measures like interitem correlations and Cronbach's	The reliability of the User Experience Questionnaire is mainly assessed using Cronbach's Alpha. Significant correlations between UEQ scales like	Inter-coder reliability was used to identify the level of agreement between different coders> This was used to identify and correct inconsistencies.

Criteria	Chapter 4	Chapter 5	Chapter 6	Chapter 7
		Alpha to ensure subscale reliability and consistency. Exploratory Factor Analysis (EFA) further refined the survey, identifying key factors like Focused Attention and Perceived Usability. This process, which included eliminating redundant items, resulted in a valid and reliable tool for assessing user engagement in online shopping.	Perspicuity, Efficiency, and Dependability with task completion times, suggesting their effectiveness in measuring user experience. Additionally, comparisons with the AttrakDiff2 questionnaire validate the reliability of UEQ scales. Most subscales exceed the 0.7 threshold for Cronbach's Alpha, indicating a high level of reliability for the English version of the questionnaire.	
Language	Conducted in English	Conducted in English	Conducted in English	Conducted in English

2.2.4 Ethics

The ethical approach for the studies in the thesis were aligned with the guidelines set by the FST Research Ethics Committee (FSTREC) at Lancaster University [200]. The process involved submitting an ethics application to FSTREC, particularly when the research included human participants, involved potential ethical risk factors, and was not reviewed externally. The application needed to be in accordance with the university's guidance, considering ethical considerations during the pandemic.

The purpose of obtaining ethics approval was to ensure participant, researcher, and public safety and wellbeing, maintaining Lancaster University's reputation for impactful and ethical research. The process involved submitting applications through the Research Ethics Application Management System (REAMS), undergoing a review process that could include amendments and re-reviews until final approval was granted.

The ethical review aimed not only at methodological assessment but also at ensuring ethical integrity in research design, data storage, and participant interaction. The emphasis was on safeguarding participants' safety and wellbeing, considering the impact of participation, and maintaining transparency and accountability in the research process.

This statement confirms that all studies within this thesis obtained ethical approval, ensuring an approach that was comprehensive, adhering to institutional guidelines, and focused on ensuring the integrity and ethical soundness of the research conducted. The approvals were made under submissions FST18098 and FST19169 for Chapter 4 and Chapters 6 and 7 respectively and the Master Coursework for Chapter 5 (this study was in concert with Lancaster University Computer Science Master students) for which the ethics approval form was submitted to Moodle as part of the coursework submission with Dr. Abhijit Karnik and Dr. Stephen Houben. An example participant information sheet is provided in appendix D.1.[2]

[2] 2 Chapter 5 was conducted in concert with SCC.402 Masters Students at Lnacaster University as part of their coursework. The author of this thesis major contributions were study design, literature review and results analysis. The author also wrote the study up for publication [235]. Appropriate attributions for this published paper have been made.

Chapter 3

Related Work

3.1 Education

To address the research questions, the application domain of education and the research in the field of VR requires investigating. By examining the existing literature on education, the pedagogical approaches can be identified, including learning theories and instructional strategies that have proven effective in various educational contexts. This information helps us understand how these elements can be adapted or integrated with VR technology to enhance teaching and learning experiences. Furthermore, reviewing the literature on education allows us to identify any gaps or shortcomings in the current understanding of educational practices. This knowledge can inform the development of VR solutions that address these issues, thereby contributing to improved educational outcomes. Additionally, examining the research on VR in education provides insights into the challenges faced by educators and institutions in adopting this technology.

3.1.1 Technology Enhanced Learning

Three terms are used interchangeably throughout the literature to describe the process of using technology within education - eLearning, blended learning and TEL. eLearning generally refers to the platform, typically customised institution-based platforms such as Moodle or Massive Open Online Courses (MOOCs). Blended learning is the pedagogy – i.e., how the module or course is built (including flipped learning). TEL appears to be the prevalent term in referring to the whole overarching concept [93, 124] of using technology within teaching.

Technology enhanced learning (TEL) refers to the assistance and improvement of the learning process via the use of technology. This may comprise a variety of tools and resources, such as online learning platforms, educational software, virtual and augmented reality, and mobile learning applications. TEL can assist make learning more interactive, engaging, and accessible for students, as well as support the work of educators and trainers by offering new ways to distribute content and evaluate learning results.

TEL has been transformative in the education sector. A meta-analysis [157] of over one thousand studies found that students performed better in conditions that were a blend of face-to-face learning and online learning versus students that experienced face to face teaching only. TEL has the capacity to improve the student experience and promote collaborative behaviours [45, 62]. It has been praised for enhancing the teaching of traditional subjects and in exposing and preparing students for the modern technology centred workplace [74]. However, there are still significant barriers to its adoption and effective use by educators. Identifying the barriers educators face in deploying and using these TEL platforms is critical to widening their use.

Technology-enhanced learning mediated through apps and games can support scaffolding strategies [151]. Sotiriou and Bogner [242] identified that technology like AR can elevate students' interest and motivation, leading to them developing enhanced investigation skills while gaining topic knowledge. It can thus be inferred that the advantage of using technology-mediation for reflective tasks such as categorising, organising, differentiation and interpretation. This includes examples of reflective activities currently used within education like white-boarding and mind maps [2, 192, 271] which are also used outside classrooms in other creative activities. Online learning platforms such as Coursera, edX, and Khan Academy have enabled millions of people throughout the globe to have free access to high-quality educational content. Studies indicate that the learning outcomes of students participating in MOOCs are equivalent to those of those enrolled in traditional in-person courses [111].

Emerging areas of TEL include adaptive learning systems [183] that utilise data and analytics to personalise students' educational experiences. By analysing student interactions with the system, the system can modify the teaching content and pace to meet the unique requirements of each student. In addition, adaptive learning systems often incorporate intelligent tutoring systems that employ artificial intelligence to provide students with individualised education and feedback. Another emerging area is game-based learning methods where improved student engagement and motivation are also being investigated [40, 96, 187]. These studies establish that these systems enhance student learning outcomes, notably in mathematics and science. Game based learning can be utilised in several fields, including as coding, engineering, and reading.

3.1.2 Computing Education

Education in computer science has become increasingly significant in today's society due to the increasing impact that technology has on our lives. As a consequence, there is growing interest in the research of computer education, with the primary goals being the improvement of pedagogy, the development of curriculum, and the construction of effective teaching approaches.

The creation of successful curricula and teaching materials has been a major focus of research in computing education [67, 227]. Developing effective curriculum necessitates an in-depth knowledge of both the subject content and the demands of the pupils. Moreover, successful teaching materials must be entertaining, pertinent, and correctly layered to facilitate student learning. Computing education research has mostly focused on techniques to enhance both the learning and comprehension of fundamental concepts in computer science [191]. Research suggests that traditional teaching methods, such as lectures, do not promote student learning or comprehension of concepts in computer science and are therefore ineffective. It has been found that active learning practises, such as learning through projects, learning from peers [236], and learning through collaboration [114], are more effective at fostering student learning and engagement.

There has also been an effort towards placing a greater focus on the cultivation of abilities related to computational thinking [275]. The examination of data and the resolution of problems are both included in the computational thinking problem-solving strategy, which makes use of many computational tools and techniques. The development of computational thinking abilities helps students in the development of critical thinking skills and prepares them for the demands of a rapidly expanding technology environment. Research in this area [267] indicates computational thinking being tightly aligned the problem-based instruction from a pedagogical perspective and game design and robotics from a domain perspective. Higashi et al. [276] combine VR and robotics with computational thinking with results suggesting that students made further progress through the curriculum versus traditional approaches.

In computing education research, the development of efficient methodologies for assessing students learning in computer science has also been a focus. Standard assessment methods, such as multiple-choice tests, are ineffective for measuring student learning and understanding of computer science concepts [8]. Performance-based assessments however, completed as coding projects, are more effective for evaluating students' computer science learning and comprehension [153].

As a key component of the National Curriculum in the United Kingdom, programming forms one of the key aims, with the ability to apply and understand fundamental concepts and principles including logic, algorithms and data representation detailed as critical components [174]. Teaching programming is a challenging task with syntax often being an early barrier to overcome. Teaching methods used to introduce programming often try to separate the syntax or language specific functions from more general logical reasoning. One approach to teaching programming to novices, particularly children, is visual, block-based programming languages such as Scratch [201]. Visual programming environments and games such as Scratch and LightBot are already well established as effective in teaching fundamental programming concepts [270]. Kalelioğlu and Gülbahar [118] identified that such tools are particularly effective in developing students' confidence in problem solving tasks. In a study of robot programming techniques, Weintrop, Afzal and Francis et al. [270] establish that block-based programming enables programming novices to quickly build complex programs with no loss of accuracy versus traditional text-based programming. Programming environments leveraging a block-based model support scientific enquiry, such as three-dimensional simulations programmed in AgentCubes [109]. This adoption of block-based programming is supported by the proliferation of learning spaces that attempt to teach programming via a block-based approach [17, 52, 143] which attempt to make programming accessible to a wider audience. A specific example of a block based programming approach is Kodu Game Lab [246], consciously designed to simplify the learning process and foster creativity and problem-solving skills in a fun, engaging virtual environment.

Overall, computing education research has made substantial contributions to the development of effective pedagogy, curriculum design, and computer science education assessment. Since technology continues to play an ever-increasing role in our everyday lives, there is an increasing demand for high-quality computer education that prepares students for future industry demands. The primary objectives within this domain are to refine pedagogical methods, curate effective curricula, and construct robust teaching approaches that resonate with the evolving educational landscape. Particular focus is directed to enhancing the learning and comprehension of fundamental concepts in computer science, a discipline pivotal in today's tech-centric world. Traditional teaching methods, predominantly lecture-based, have shown limitations in fostering deep understanding and engagement, particularly in complex areas such as computational thinking. This situation underscores the necessity for innovative, interactive educational tools and methodologies.

3.2 Related Pedagogy

According to Shulman [232], pedagogy broadly refers to "*the types of teaching that organise the fundamental ways in which future practitioners are educated for their new professions*." As such, pedagogy is concerned with the actual mechanics of teaching, including the best methods for doing so and defining best practise, such as values, attitudes, and beliefs.

It is initially beneficial to recognise historical and contemporary learning theories and their related methodologies in order to identify factors that influence learning and their effect on the achievement of learners. Petty [193] describes a variety of learning theories that can be categorised into four fundamental paradigms: social, constructivist/cognitivist, behaviourist, and humanistic. According to Petty, there are numerous similarities between the ideas, but they also take completely diverse approaches. Depending on the circumstances, one theory may be more applicable than another, or a combination of ideas may be effective. It is useful to examine each theory in further depth to identify its optimal application.

3.2.1 Cognitive Development

Piaget (cited in Morra et al. [168]) considered that cognitive growth occurs in a sequence of stages connected by competence, giving rise to the idea of cognitive development. Experience gives learners their first understanding, and new experiences and analysing the differences between the old and the new experiences help them gain greater understanding. Morra et al. continue by stating that Piaget himself was aware of the limits of his theories, including the fact that they were based on his own three children and other subjects with similar educational backgrounds. According to Santrock [218], Piaget also had a propensity to underestimate children's capacities when, in fact, current theory says they are much more capable. For instance, they have the capacity to adopt another person's perspective which went unconsidered by Piaget. The process of storing information in memory and retrieving it as needed is comparable to an HCI (Human Computer Interaction) theory called Nielsen's 10 Heuristics of Interface Design. One of these heuristics, according to Nielsen, is recognition rather than recall, which means that by making options or actions accessible and reducing the user's memory load, the user need not explicitly remember what they need to perform. Thus, the action they adopt is logical. Piaget's schemas can be used to impact teaching in the same way that this heuristic can be used to enhance the design of applications. For instance, establishing a profile from a learner's former academic journey enables the teacher to preserve a learner's cognitive process. In professional practice, educators strive to tie classes to learners' talents and interests so that their experiences are expanded upon and their behaviour, such as in programming, becomes intuitive. Petty [193] states that a crucial component of the cognitive approach, building on these prior experiences, also enhances student engagement. The fact that Piaget's theories are primarily focused on children's learning and that they predate the idea of paragogy is one of their key disadvantages. Therefore, the term 'neo-Piagetian' was coined to describe a branch of research that drew on Piaget's work and specifically examined adult learning and how Piaget's theory of cognitive development may be applied to it.

When considering the incorporation of VR with education, the theoretical frameworks employed are typically based on Piaget's understanding of the development of learning and instruction [63]. For illustration, instruction uses VR as a form of technology, and students are responsible for their own use of the technology within the context of an environment in which they struggle with concepts independently and do so within a constructivist framework. According to Piaget's theories [194, 195] children need to interact with physical characteristics in a self-directed setting that allows them to feel the struggle of sorting and storing difficult information at their own pace. This is necessary for students to be able to go through the learning process. Students are given the opportunity to establish their own methods for comprehending the new information using this framework. Because it gives students some measure of control over their own education, this method of instruction is extremely effective.

Using a sandbox structure is by far the most prevalent way to combine Piagetian theories with VR [199]. As an illustration, students first receive a traditional lecture on the physics principles in a setting that does not employ VR technology. After students have completed the lecture, they are given the opportunity to interact with a VR sandbox that has been preconfigured to represent the topics. This educational technique is an example of a Piagetian theory because students are permitted to independently explore physics principles in a VR environment without the requirement for mathematical computations. This is because students are given the opportunity to work independently through the curriculum, allowing them to develop their own understanding.

3.2.2 Blooms Taxonomy and Learning Styles

Bloom's Taxonomy is a framework that was created to categorise educational objectives in terms of explicit and implicit cognitive skills and abilities. The framework consists of six categories, each of which is harder to achieve than the last and builds on the prior in a cumulative structure. Since the framework was first created in 1956, there have been several developments in linked educational and psychological sectors. Bloom's Taxonomy was amended in 2001 by Anderson and Kratwohl [10]. Since most contemporary research refers to the new version of Bloom's Taxonomy rather than the original, this revised form will be further examined in this section. The biggest benefit of using the new version, according to Forehand [81], is the seemingly insignificant but yet significant change of category names from nouns to verbs. The terminology modification reinforces the focus on presenting Bloom's Taxonomy for usage by a much wider audience than that which was originally intended in the first version. The six modified categories, according to Anderson and Kratwhol, are remembering, understanding, applying, analysing, evaluating, and creating. They correspondingly replace the categories of knowledge, comprehension, application, analysis, synthesis and evaluation (see figure 3.1).

Forehand [81] and Anderson and Kratwohl [10] identify remembering as the process of retrieval, recognition, and recall of pertinent knowledge from long term memory when describing these categories. Understanding, according to Forehand, is the process of creating meaning from a variety of sources, including oral, written, and graphical material, by using techniques including summarising, interpreting, inferring, and classifying. Applying is the act of carrying out a technique, while analysing is the process of breaking down information into its component pieces and figuring out how those parts relate to one another and to a larger structure or story. Finally, Forehand defines the final category of creating as synthesising a thought or coherent argument based on previously identified co-joined elements or producing something new by restructuring elements via generation, preparation, and production. Evaluating is the method of making judgments using a set of standards and criteria combined with validation and critical thinking.

Every one of us learns through a wide variety of distinct processes, and the particular strategies that are the most successful for us are very variable from person to person. In their classification scheme for interactive computer-aided software, Montgomery and Fogler [167] noted that in addition to using Bloom's

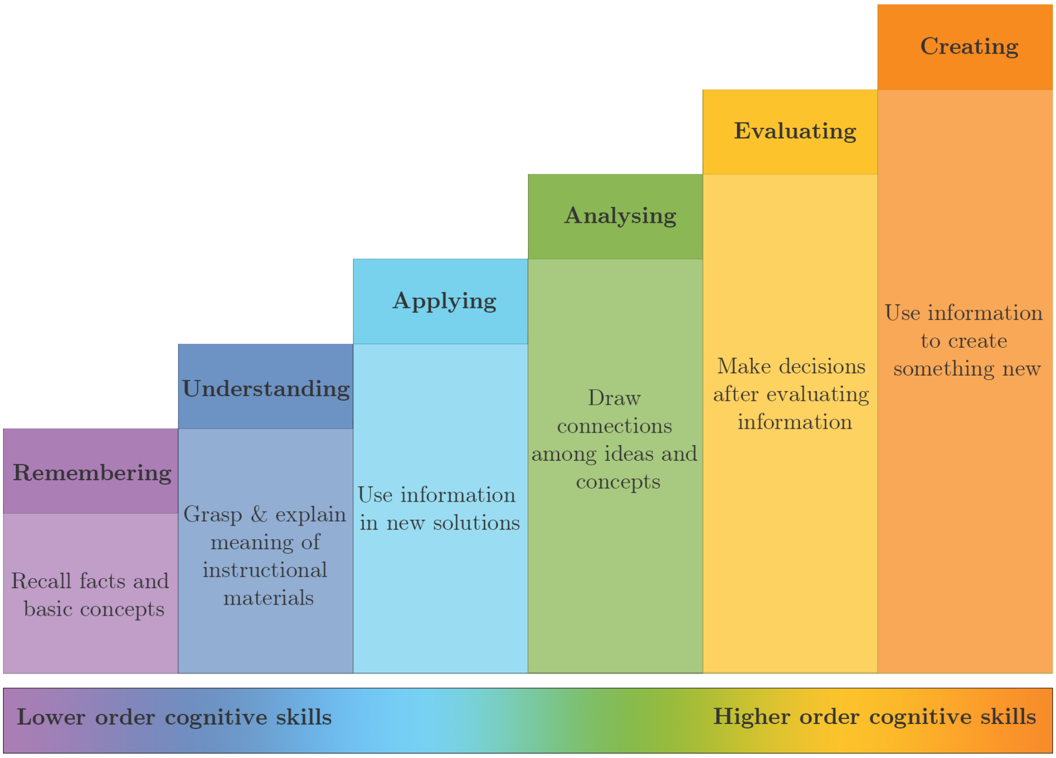


Figure 3.1 Blooms revised taxonomy.

Taxonomy to identify skills to be practised, it is vital to determine the most effective ways to instruct the pupils, taking into account the students' unique learning styles. Numerous researchers [76, 130, 244, 260] have investigated these various learning styles and established classification systems for the purpose of determining the preferred learning and teaching methods of individual students as well as educators. These classification schemes can be found in a variety of academic journals. For example, Felder and Silverman [77] devised a classification scheme that measures the preferred learning styles of students along five different scales or dimensions. They also came to the conclusion that the preferred teaching method of the majority of engineering faculty in general does not align with the optimal learning method of the majority of engineering students. This is because in general engineering students learn most effectively via processes that are sensory, visual, inductive, and active, whereas the majority of lectures tend to be intuitive, verbal, deductive, and passive in nature. A more in-depth discussion of how Felder and Silverman's learning styles and Bloom's Taxonomy can be utilised in conjunction with one another to influence the development of instructional software in Montgomery and Fogler's article.

Outside the research community, educators often subscribe to the myth that a learner has an immotile preferred learning style and only teaching by accounting for that style will achieve good outcomes. This myth has long since been debunked across various literature [33, 83, 84, 172], with the common consensus now being that learners respond better to different styles at different stages in their learning journey, often in the same session. This newer understanding promotes the concept of multi-modal delivery that accounts for multiple learning styles. VR is ideally placed to not only leverage multi-modal teaching that builds upon our understanding of Bloom's Taxonomy and learning styles but to also push our understating further and question and refine our current approaches.

3.2.3 Scaffolding

The term scaffolding refers to a process that, according to Wood et al. [277], allows an inexperienced student to solve a problem or complete an activity that is beyond their present ability level. Shepard [228] defines scaffolding as the support provided by educators' during problem-solving in the form of reminders, tips, and encouragement to ensure that a activity is completed successfully. Scaffolding can be used to ensure that a task is successfully completed. The gap between a student's present talents and his or her potential growth that could occur with scaffolding is explained by the term 'zone of proximal development' [265]. The zone proximal development (ZPD) is defined by Roth and Jornet [207] as the difference between what a student can achieve on their own without aid and what they can achieve with guidance, either from a teacher or through peer cooperation. Vygotsky [265], a psychologist, proposed the idea, and he usually agreed that it was advantageous to offer tasks that fall within a learner's ZPD that would promote their particular learning. This is in line with the flipped classroom principle, where a teacher can focus on providing resources to the students who need more individualised attention and make use of the collaborative work time that has been freed up during class.

Therefore, scaffolding refers to the assistance and direction provided by teachers or other educators to help pupils acquire new skills or concepts. The objective of scaffolding is to offer students with the necessary support to develop their comprehension and independence, while progressively reducing the amount of support as they become proficient.

The literature shows that scaffolding can take numerous shapes, including:

- *Modelling*: A teacher shows a topic or concept to students by breaking it down into manageable steps.

- *Guided Practice:* Students are given the opportunity to apply new skills or concepts independently, with the teacher offering support and direction as necessary.

- *Feedback:* The teacher provides students with thorough and precise comments on their work, enabling them to discover areas for development and establish learning objectives for the future.

- *Collaborative Learning*: Students collaborate in small groups to complete assignments or solve problems, with the teacher offering help and direction as necessary.

Scaffolding is thus a crucial component of the teaching and learning process because it ensures that students may build on their existing knowledge and abilities to attain their maximum potential. It is also crucial to highlight that scaffolding may be utilised to support students of varying ages and ability levels in any learning situation, not just the classroom.

It is possible to have static or dynamic scaffolding [230, 278]. Static scaffolding is scaffolding that does not change while education is taking place, whereas dynamic scaffolding is scaffolding that changes via the use of personalisation techniques in order to be matched to the capabilities or requirements of the pupils. Research has demonstrated that adaptive scaffolding shows a beneficial impact on the learning outcomes of students when it is implemented in games [212], intelligent tutoring systems [247], and other e-learning applications [278]. Chen et al. [43] designed a portable bird-watching apparatus that features a mechanism that resembles scaffolding. The mechanism of the scaffolding can be altered to provide varying degrees of support for each individual learner. An outdoor activity for bird viewing served as the testing ground for the programme, and the researchers concluded that using the application assisted students in improving their learning outcomes over using a guidebook. Conversely, other research has shown static scaffolding is successful in improving the learning outcomes of students by utilising it in concert with procedural scaffolding [106] or learning second language vocabulary [141].

In respect of VR, scaffolding mechanisms have been shown to have a positive and significant effect on the learning outcomes of students by a large body of research, and more recent studies have shown that computer-mediated scaffolding is more successful than lecturer-based scaffolding [65] to a greater degree.

3.2.4 Reflective Tasks and Inquiry-based Learning

Inquiry-based learning, a form of active learning [190], is a pedagogical approach that can be applied across domains and topics. Inquiry-based learning aims to trigger the advanced cognitive processes of application and analysis. Inquiry-based learning is key to stimulating students' desire to learn [125] through interest [266] or active engagement in a cognitive activity [221], such as mind mapping, due to situational interest [145]. Scaffolding is one of the key strategies for effective inquiry based learning [50, 214]. Inquiry-based learning relies on interest [145] or active engagement in a cognitive exercise. Situational interest arises from the appeal of the actual activity to the learner rather than their predisposition towards the topic [145, 221]. Interest plays a core part in regulating our emotional engagement in undertaking a task [220], what we choose to learn [266], and the efficacy of learning that information [22]. Situational interest arises from the appeal of the actual activity to the learner rather than their predisposition towards the topic [145, 221]. When designing educational tools, situational interest is a core consideration as it also develops personal interest for learners and is beneficial to positively enhancing learning [101]. Designers of educational tools can exploit situational interest to develop personal interest for learners and enhance learning. The challenge is how to exploit situational interest in technology-based applications while simultaneously providing a scaffolding tool that assists the inquiry process for students and the overall learning experience. Scaffolded inquiry-based learning allows learners to discover information semi-independently of the teacher and/or classroom. The learners present the discovered information, by way of modelling outcomes and through think-aloud activities. Finally, they reflect on the pieces of new information or what they have learnt.

Inquiry based learning forms one of many innovative modern approaches to learning. Kirschner et al. [125] state that inquiry based learning is stimulates a students' desire to learn more, discover information semi-independently of the teacher and/or classroom, develop the ability to construct ways of presenting discovered information and finally a way to reflect on the effectiveness of discovering and presenting new information. To make this minimally guided learning strategy effective, sound scaffolding strategies need to be implemented [50, 90, 112, 215, 257]. Scaffolding allows learners to engage in tasks that otherwise might be too complex for them to manage given their current abilities. Examples of scaffolding include undertaking reflective tasks, such as mind mapping, diagramming or diary keeping and using technology-based solutions, such as applications and constructing websites to display information.

VR as a relatively new technology can leverage inquiry-based learning to improve educational outcomes beyond the usual scope of topic specific simulations, i.e., it is well placed to exploit topic agnostic approaches. In the context of education, '*topic agnosticism*' refers to an approach where the teaching methodology or learning platform is designed to be independent of any specific subject or topic. This means that the approach or platform can be applied across various disciplines and content areas without needing significant modifications. Topic agnosticism is advantageous because it permits the creation of flexible, adaptive, and reusable teaching and learning materials. Instructors may use the same techniques or resources to teach a variety of disciplines, hence enhancing the efficiency and cost-effectiveness of the educational process.

In Kolb's [130] model of experiential learning, VR may serve as a suitable stand-in for the actual experiences that are traditionally required [42, 132, 213]. In addition, a number of studies have led academics to the conclusion that it is important to incorporate technology within inquiry-based learning, and they advise using technology-supported educational experiences for inquiry-based teaching [16, 69, 122, 123]

3.2.5 Collaborative Learning and Paragogy

Research has shown that student learning can be improved by the usage of collaborative activities [149, 150]. Thus, researchers recognise that the social context in which the processes of knowledge building takes place has an effect on the outcomes of educational activities. Students get the opportunity to communicate their own ideas and understanding when they participate in collaborative learning tasks, which is one of the reasons why collaboration has positive impacts.

Students given the opportunity to articulate and investigate their own theories and ideas through the use of inquiry-based learning activities in a collaborative setting demonstrate improved agency [248] . Students are required to make a number of decisions throughout the course of inquiry-based learning, such as which propositions to test and which variables to alter. Within the context of collaborative inquiry-based learning, students are encouraged to discuss their plans and ideas with the person with whom they are paired. This implies that when students work together on a project, they need to 'externalise' their ideas. This means that they need to offer their partner justifications and explanations so that their collaborator can comprehend and evaluate their plans and ideas [254]. It is believed that encouraging students to externalise their thoughts and ideas will improve their perception of errors and contradictions in their own theories or analysis, as well as inspire them to revisit their original ideas. Okada [180] conducted research in which they compared the inquiry-learning behaviours of individual students to those of dyads of students within the context of a molecular biology classroom. They concluded that dyads explored more potential alternate hypotheses and carried out more insightful trials compared to individuals. The learning partner's inquiry or remark would frequently serve as the impetus for the development of an alternative hypothesis. Students need to be able to identify information that is inconsistent in order to reap the benefits of teamwork, and they must have access to the information, knowledge, and skills necessary to resolve the inconsistency [88, 263].

Paragogy describes peer-to-peer learning where students provide a supportive structure for each other to learn and grow [53]. It is a heutagogical method of learning that builds on the idea that the learner is the initiator and main agent of acquiring knowledge [97]. This places paragogy in an ideal position when considering remote and independent learning activities. It is a branch of collaborative learning in which students work together to accomplish a common objective or learning outcome. It characterises the collaborative creation of information, skills, and understanding by peers. The following are characteristics of paragogy:

- *Collaborative*: Paragogy is a collaborative method of learning in which students work together to accomplish a common objective or learning outcome.

- *Self-directed*: In paragogy, pupils choose and pursue their own learning objectives.

- *Social*: Paragogy is a social learning method in which students learn via connection and participation with others.

- *Peer-to-p*eer: Paragogy is a peer-to-peer method of education in which students learn with and from their peers.

Paragogy is applicable in a range of contexts, including schools, online communities, and workplaces. It may be used to enhance learning across a wide range of topic areas and ability levels, and it can be an effective means of promoting student-centred and self-directed learning.

Researchers have explored paragogy through tutor-led activities, Learning Management Systems (LMS) [268] and mediated through VR [1]. In such systems, the tutor establishes the thematic organisation of the learning content and identifies the activities which require students to engage in paragogy. Collaboration has been studied extensively for its benefits of improving cognitive abilities, skill attainment and the transfer of knowledge to peers in education [274]. Plass et al. [197] demonstrated that collaborative learning games promote situational interest and a desire to repeat learning exercises. Collaboration in peer learning enables peer feedback in absence of teacher participation [72] and enhances students' exposure to unexplored strategies, solutions and points of view [158]. There is evidence to suggest that technology which mediates connections between peers [99], through collaborative virtual learning environments, allows students to connect and share information in ways that are not possible in real life [135].

Experience with LMSs suggests that the structuring of learning content and activities is driven by the tutor or institution, with student-focused elements such as interaction and discussion being under utilised [239]. Unlike students, educators are well equipped to create scaffolding based on pedagogical principles. However, paragogy can manifest beyond peers simply contributing to an overall product (e.g., a presentation or other educational artifact). Paragogical activities, which occur outside of the planned learning, can also occur during periods of self-study. While some learners may be highly motivated, they often lack the tools and understanding to suitably scaffold their own learning activity within a self-study (or group-based study) session. The positioning of a study investigating mind-palace techniques and paragogy through an artifact called CleVR [236] is within this gap where paragogy occurs outside of activities planned by the educator, and instead is a student-initiated activity which builds towards another activity (e.g., study preparations for exams). Such a tool can scaffold the learning activity through well-understood pedagogical approaches leaving the learner unencumbered to focus on the actual learning.

3.3 Virtual Reality

A technology that is growing in the education sector is VR. VR can be defined as "*a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world)*" [229].

The pace at which technological advancements in the realm of VR are taking place is unprecedented. New research, presentations and conference demonstrations of the various systems and applications used within VR appear multiple times each week. Nevertheless, it is worth exploring the origins of VR in order that its future direction may be anticipated.

3.3.1 Origins

Sutherland [249] presented his vision of a display mimicking the real world in all its senses fifty years ago. The concept of Virtual Reality was created by Lanier in 1987 [137] by combining the concepts of many technologies supporting sensory stimulation. Sutherland's vision was realised not only because technology and algorithms were developed but also because a hype was created. Initial commercial systems based around gaming applications attempted to capitalise on this nascent market opportunity. Two notable examples were the Virtuality system based on Amiga hardware and Sega VR on the Mega Drive hardware, two of the most powerful systems available at the time. Researchers saw the potential despite the initial euphoria and continued to pursue it despite its collapse after a few years due to hardware failing to match or keep up with user expectations. ACM VRST and IEEE VR conferences and journals such as Presence have regularly published accomplishments and new insights in this space.

Almost twenty-five years after the initial wave of VR, a Kickstarter campaign launched in 2012 by the name of Oculus Rift [179]. This was the primary catalyst that led to the so-called second wave of VR, which is the development effort that is occurring currently. However, this time around, developmental HMDs aimed at researchers are significantly more affordable, and the results of research conducted over the course of the previous twenty-five years are being re-analysed in light of this new technology to see if the assumptions and conclusions previously made are still valid and correct. Many of these new products entering the market and are close to Sutherland's vision of the Ultimate Display.

3.3.2 Virtual Reality and Interaction Design

VR is capable of providing experiences and producing results that cannot be obtained in any other way. However, creating immersive applications is not always straightforward, and simply providing the user with an interface to achieve their goals is not sufficient. It is also about users interacting in a straightforward, pleasurable, and frustration-free manner. Despite the fact that VR systems and applications are highly complicated, it is the role of designers to guarantee that the VR application naturally explains to users how the virtual environment and its tools function, allowing users to accomplish their goals in a way that combines to provide a graceful and pleasant experience [41]. The burgeoning area of VR interaction design strives to create and build effective ways for people to interact with virtual worlds. Some significant outcomes have been established through considerable study that can enhance the overall VR user experience.

Studies have highlighted the significance of immersion in VR interface design [30, 107]. Immersion refers to the extent to which a user feels physically present in a virtual world, and it is essential to a good design. The employment of techniques such as realistic images, intuitive user interfaces, and authentic soundscapes has been found to promote immersion. Bowman and McMahan [30] investigate the idea of immersion in VR and its influence on user experience and interaction design. They suggest that the level of immersion in a VR system is a significant aspect in determining the system's overall usefulness and success. Many factors of immersion, such as visual, auditory, and haptic components, as well as the sense of presence, which is the subjective feeling of being inside a virtual environment, influence the level of immersion apparent in a system. There is a connection between immersion and a variety of elements, including user duties, system capabilities, and user preferences. Bowman and McMahan argue that there is no universally applicable solution to the question of how much immersion is sufficient. Instead, they believe that the appropriate level of immersion for a VR application relies on its environment and objectives. For determining the proper level of immersion, they propose that designers carefully assess the needs of the targeted user population and the intended tasks.

User-centred design has been acknowledged as a significant driver of effective VR interface design [281]. This methodology places the user's requirements and preferences at the centre of the design process. It is vital to involve users in the design process and perform user testing and assessments in order to create successful VR interaction designs that meet their demands. Moreover, user-centred design affords application builders the opportunity to account for accessibility and inclusiveness to guarantee that VR experiences are useable by all users.

VR interaction design research has also focused on designing for several interaction types, including object handling, movement, and social engagement [14, 32, 171]. To assist these interactions, researchers have investigated several strategies, including hand tracking, haptic feedback, and avatar embodiment. However, there is still much progress to be made before a standardised set of interaction methods can be determined for VR with some deficiencies still evident. For example, natural hand gestures have been demonstrated within VR. They have not however found to be more effective than conventional input devices such as a keyboard and mouse for manipulating objects, although they may be more intuitive [142].

Early research [103] identified that users have difficulty understanding three-dimensional space. Interaction recommendations from these early studies included using ray casting for target acquisition coupled with a 'silk cursor' to provide feedback and context to the user [286]. Further research [261] identified design strategies to allow users to estimate size and distance within virtual worlds by way of providing landmarks and reference objects that act as visual clues. With the recent advances in virtual reality hardware in terms of both headsets and controllers, recent research has centred on implementing real word interactions within the virtual world [134, 155, 171]. However, there's an inherent risk that the designed interaction can end up being worse than low fidelity interactions [156]. The balance between implementing natural, low fidelity and metaphorical interactions is an important factor in the user experience associated with VR application design.

A peculiar interaction challenge for VR interaction is the issue that it is often difficult to perceive depth within without visual clues, despite the stereoscopic nature of VR. There is also the question of accessibility for those that suffer from lazy eye (amblyopia) which negatively impacts depth perception. Some research has been done to address this issue. Teather and Stuerzlinger [255] compared the performance of one-eyed and stereo cursors when pointing at 3D target projection. They found that in terms of accuracy, stereo cursors performed much better than one-eyed cursors for target selection, yet there was no significant difference in response time. This confirms that stereo cursors provide greater depth information, enabling more precise aiming. Another interesting finding in this study was that participants were also able to point with more precision when the cursor was situated at the fingertip as opposed to the base.

Related to depth perception is designing interactions that allow for the selection of occluded objects with 3D environments. A study by Yu et al. [284] looked at the development and evaluation of a new technique called Depth Ray for selecting fully-occluded targets in VR. The Depth Ray method combines ray casting with depth adjustment, which enables users to reach and select occluded targets without moving around the virtual environment. This is especially useful for situations where the user's physical movement is limited, such as in restricted classroom settings that dictate the need for seated experiences or students with limited mobility.

Feedback is another important consideration within interaction design for virtual environments. Haptic feedback for hand motions [14, 22] can assist in immersion but requires special hardware. Immersion can be also enhanced by audio cues in digital experiences [71]. Sound plays a critical role in providing essential feedback to the user, such as providing warnings, indicating errors or confirmation of user actions [116, 117, 184] and sound quality has greater effect than image quality on presence [56]. Low-cost commercial VR headsets generally lack high-fidelity haptic feedback controllers but support higher quality sound. With VERTIAS, a decision was made to exploit audio feedback to augment visual feedback for specific notifications during interaction.

Researchers have noted the necessity of addressing possible negative consequences of VR interaction design, including cybersickness, discomfort, sensory overload and even how users exit the VR experience [127]. These impacts can be mitigated by minimising latency, maximising frame rates, and building comfortable and adaptable headgear. The most common physiological issue with VR is simulator sickness resulting from visually induced motion. Hettinger et al. [100] identified that vection and motion sickness occur at the same time and further studies have shown strong links between both [47, 134, 245]. Vection is even more pronounced in VR systems that only employ 3DoF (Degrees of Freedom) versus a 6DoF through their hardware.

To conclude, the primary research outputs for VR interaction design stress immersion, user-centred design, planning for multiple types of interactions, and addressing any negative consequences as key considerations. As VR technology continues to grow, further research is required to enhance the user experience and develop designs that meet the demands of users.

3.3.3 VR Within Education

VR adoption has been explored in various fields, including applications in the tourism [26, 68, 258], gaming [110], firefighting [272], the legal profession [283] and construction management [4]. Over the last 20 years, VR has seen a rapid advancement in both technology and application development. The miniaturisation of components has also seen the need for headsets being tethered to a PC being eliminated, further enhancing the accessibility of the technology to educational institutions.

VR is well-established as an educational tool throughout a broad range of fields. These tools operate as a custom environment and require interactions to simulate real-world tasks. For example, VR educational tools in the medical field allow clinical protocols to be simulated, practiced [95] and assessed [73] risk-free, thus enhancing student learning. Similar results are observed in engineering by Kaufmann et al. [121], where students found the Construct3D tool easy and quick to learn and appreciated the tool's ability to let them experiment with their ideas. There are demonstrable advantages of supporting reflection to explore a specialised topic but limited to an environment similar to where the knowledge would be applied.

Technology-enhanced education focuses on scaffolding student's engagement in the subject through attention and immersion [170, 226]. VR enhances attention [177], increases motivation [86] and inspires self-directed discovery [105] through different interactive applications like virtual proxies of learning locations [203] and learning tools [28]. For a practical approach to pedagogy in VR, media and resources play an important part in the learning process of the users. Considerations need to be made when designing interactive elements catered for the practice of teaching. This includes deploying reusable elements in teaching and passing on material for other didactic purposes [219].

A key strength of VR assisted learning experiences is the detailed visualisation of objects [240, 280]. Visualisation creates variety of stimulation which in turn increases memorability of experiences [173]. Systems like iScape [27] visualise the semantic relationship within learning content. In VR, text can be replaced or augmented by videos or 3D objects that learners can watch, hear and interact with. Visualisation, audio and interactivity lends itself well to the different learning styles described within the VARK learning styles model [80]. Suitable design ensures learners have a multi-modal approach to learning styles. Kolb [129] classifies learning styles within a two-dimensional learning space, delineated by '*Abstract Conceptualization - Concrete Experience*' and '*Active Experimentation - Reflective Observation*'. Even outdated research [42] that considers learning styles in the traditional sense highlight that VR is beneficial across all the previously conceived learning styles, inadvertently strengthening the argument for VR as a true multi-modal delivery method.

Students engagement in the learning process has the potential to be significantly enhanced by VR [177, 185]. By allowing users to interact with objects within a 3D space, VR offers pseudo-physical interactions [165] that contributes to a sense of presence in the virtual world, increasing engagement. With past low-cost devices such as the Oculus Go, haptic feedback and true six degrees of freedom movement were not possible. However, with the advent of the Meta Quest 2, this is now available at an entry level price point. These entry level devices extend the use case scenario of VR in education, with the potential for VR being included in an institutions flipped learning strategy [1], allowing students to learn key concepts away from the classroom. In applying cognitive development to a flipped classroom context, according to McLaughlin et al. [154], because the flipped classroom is student-centred, each student is expected to arrive at class with a foundational understanding of the ideas and material that will be covered. The order in which the materials are presented creates a setting where the student can work at their own pace and under their own direction, two traits that are common in adult learners [51], and frequently encourages peer-based learning (paragogy). Teachers then add counsel and direction to this, inspiring the students to think imaginatively and develop their own ideas. According to McLaughlin, this unfettered process of learning fosters important cognitive growth.

A direct and well understood benefit of VR in education is the capacity for it to motivate learning within students. Although initially considered to be a novelty effect, studies [178] have demonstrated this not to be the case. Bogicevic et al.

[26] concluded that VR "*induces higher elaboration of mental imagery about the experience and a stronger sense of presence*". Medical procedures, including intubation, laparoscopy, and eye surgery are fields where VR being used in training [209, 241] is strong. A study by Alhalabi et al. [7] investigated the impact of VR on students' performance within an engineering discipline compared to traditional teaching methods. The results revealed a significant improvement in students' achievement and understanding of complex engineering concepts when VR systems were incorporated into their learning process. The researchers attributed this to the immersive and interactive nature of VR. This allowed students to visualise and manipulate 3D models, enhancing their spatial abilities and problem-solving skills. The study also found that students in the VR group were more engaged and motivated, resulting in higher retention and comprehension of the topic and the material therein. In a business class, VR was tested as a content delivery platform, with positive results including students reporting greater enjoyment and interest in the learning activities [140]. Community learning via VR is also an active field of research. In Wako, Japan, citizens utilised VR to experience an immersive model of a supernova [108]. This study found that well-produced and engaging 3D videos in VR had a positive impact on both learning outcomes and interest in astronomy. The use of visualisations, animations, and real-world examples assisted in making abstract concepts accessible and relatable. The authors also identified the importance of using storytelling and narrative techniques to capture the viewers' attention and enhance their understanding of the subject matter.

Interactive and tangible objects within VR have been shown to promote engagement and when coupled with existing game-based learning activities provide an environment where effective learning can take place [152]. While not a VR application, this idea was explored by Melcer and Isbister [159], finding that tangibles had a positive impact on interest and enjoyment of programming. Bell et al [20] provides a comprehensive evaluation of VR as an educational tool. They point out how VR also provides the opportunity to improve teaching methods where 'traditional' methods may not be as effective. Based on Felder and Silverman's [76] learning styles for example, they show how VR can help sensory learners by presenting "*tangible representation of abstract concepts*". Concurrently, falling costs of VR devices has lowered the entry barrier for the adoption of these devices into classrooms and as devices in the home. Recent studies [52] have explored the potential and effectiveness of leveraging VR-based teaching, with games being more effective than simulations and virtual worlds in improving learning outcomes.

Systems that use VR for programming education have been researched but are rare. Chandramouli et al. [39] detail teaching programming concepts to engineering students via a VR system. This system uses the archaic VRML97 specification to provide limited interaction and graphics quality and targets young adults. A virtual 3D programming language for novice users is described by Ortega et al. [182]. As a practical 3D extension of Scratch, it uses a 3D-VPL environment to allow for creating relationships between boxes. Teaching of ordering algorithms is tackled by Grivokostopolou [92], however it makes assumptions that learners understand the concepts of sequence, iteration and bifurcation thus is not targeted at novices. Computational thinking is commonly encountered in robotics, which Witherspoon et al. [276] explore by developing a series of problems to be solved via a 3D virtual environment game based on previous work by Carnegie Mellon University and the Robomatter programming curriculum [205]. However, in comparison to existing desktop applications, there is a gap in understanding how the use of VR block-based programming games can help with understanding the foundational concepts of programming.

While VR is increasingly prevalent in education, it is subject to age restrictions that could impact its integration into educational settings. Typically, manufacturers recommend that VR headsets are not used by children under the age of 12 or 13 (dependent on region). This recommendation is primarily due to concerns about the potential impact on visual development and the neurological effects in younger children, whose brains and visual systems are still developing. Additionally, there are concerns about the physical fit of VR headsets on smaller heads and the potential for content to be unsuitable or overwhelming for younger users.

In an educational context, these age restrictions present a significant limitation, particularly for primary and early secondary education. Institutions catering to younger students may find it challenging to integrate VR into their curriculum, missing out on the immersive and interactive experiences that VR can offer. For higher education institutions, where students are typically older than the recommended age limit, VR presents fewer challenges and can be a valuable tool. However, the disparity in access to VR technology across different educational levels could lead to unequal exposure to this technology, potentially affecting students' familiarity and comfort with VR as they progress in their education.

3.3.4 Barriers to Adoption

The slow adoption of VR technologies within education appears to have little to do with its effectiveness from a student perspective [160]. Many of the barriers VR faces in its adoption within education is shared by all new technology, so it is useful to initially review the wider literature surrounding technology adoption.

While most research for using technology in education centres on students attitudes [38, 147, 273], including Human-Computer Interaction (HCI) focused research [5, 36, 55], there is some previous research that looks at the factors and issues [18, 54, 169, 225, 285] from an educators perspective. In a wide ranging review of these factors within an higher education setting, Senik and Broad [225] identify several key factors that provide barriers to technology adoption. These are primarily lack of interest; resistance to innovation; demands on faculty time; unacceptable learning methods to students; limited knowledge of technology; preference for traditional teaching methods; reluctance to change teaching approach; problems with technology itself; lack of resources; lack of intuitional support; lack of technical support [6, 85]; and, a culture of change resistance. Sangster [216] also identifies the unwillingness of some educators to experiment as a barrier which thus affects their desire to use technology in their practice. Roberts et al. [204] categorises these barriers into three distinct areas. The first is social, i.e., professional network, peers' conformity, and attitudes. The second is organisational, i.e., institutional support and infrastructure, training, and funding. The last is individual, i.e., willingness to change, learning new skills, and ability to operate out of their comfort zone. Gregory and Lodge [91] also highlight academic workload as a barrier.

While the above barriers are well described in the literature, there is a distinct lack of consideration on how educators populate new technology with educational resources. There is an assumption that educators will simply transfer over and adapt or modify existing resources. This is further compounded by the development of technologies such as VR and AR which present unique difficulties around the skill set required of educators to use them effectively. Typically, a VR world is produced using a 3D modelling application in conjunction with a software development environment such as Unity or Unreal. The necessary skills and expertise are ordinarily beyond the capabilities of the majority of educators. Not only is it vital to comprehend how educators build virtual worlds and generate and use resources, but it must also predict how they may want to use these environments and materials for these new technologies. This is the research void this thesis aims to address.

3.4 Mind mapping and Virtual Reality

3.4.1 Mind mapping Pedagogy

Mind maps as an educational tool allows learners to offset difficulties commonly ascribed to natural limitations with working memory and its capacity. Recalling and managing disparate elements of information are recognised as learning tasks with a high cognitive load [256]. Mind maps can alleviate this cognitive load by allowing the learner to interact with a graphical representation of ideas and their relationships [58]. The learners can engage in reflective tasks that otherwise might be too complex for them to manage given their current abilities. Specifically, learners can offset difficulties commonly ascribed to natural limitations of working memory and its capacity [70, 282]. It also develops students intrinsic motivation by enabling them to understand complex topics and relationships, improving their sense of competency [161]. Mind mapping is well established as an effective pedagogical tool [282]. Mind maps are implemented as an abstraction of the knowledge from the environment where it is applied. Cognitively, mind maps are closer to how the human mind organises the information than how the information is applied.

Mind maps are versatile in adapting to the available medium. The low-fidelity version can be a pen and paper activity, easily extended to a white-board and sticky notes. The information is organised in a 2D planar space with interconnecting links formed between related keywords. The digital form of this activity has been explored in the context of information organisation [19], collaborative thinking [75, 144] and as a research tool to understand collaboration between young learners [114]. Zipp et al. [289] highlight the use of mind maps as opportunities for the educator to direct and shape the conversation in a classroom around a pre-determined set of keywords. The resulting diagrams resembling spider-webs are referred to as spider-diagrams. A study by Abi-El-Mona and Adb-El-Khalick [2] found significantly higher conceptual understanding in students who utilised mind maps to explore scientific topics. In addition, research has shown that students engaged in mind mapping tasks are active participants with the teachers being facilitators [37], which aligns well with the aforementioned inquiry-based learning paradigm [15].

For students to become knowledgeable in a field they not only need to be able to recall individual knowledge, but they also need to be able to gain comprehension of how various ideas are related and in the field as a whole. Zimmarro and Cawley [288] suggest that when students are asked to create a graphical representation of their field of study, it encourages them to apply the concepts and ideas that they have previously gained, either through tutor led sessions or via their own inquiry. Students are required to re-evaluate their prior knowledge and ideas, choose information that they want to communicate, and consider links between various components that make up their representation before they can develop such a representation. According to Fischer et al. [78], activities involving mind mapping help students become aware of gaps in their knowledge of explanations and connections. Students are given the opportunity to study these missing links by participating in inquiry-based learning settings that are based on simulation. Zhang and Linn [287] stated additionally that the process of constructing a representation could encourage students to review the foundational information again. The findings of their research indicated that development of a common representation provided students with an opportunity for reflection on the uniqueness of their own concepts, leading to increased levels of knowledge integration. Students may be encouraged to integrate the conceptual information that they have obtained in an inquiry-learning environment if they are given the opportunity to develop one's own interpretation of a domain. This may have a positive impact on the collaborative learning process in addition to the inquiry-learning process [31].

When combined with inquiry-based learning activities, the production of a shared representation, such as a mind map, may yield highly significant results. When it comes to the process of collaboration, representations that were created through joint effort can assist students in achieving and sustaining a shared focus as reported by Suthers [250]. In that study, usage of a novel graph model, evidence graphs, were investigated in a peer learning environment. During the process of collaborative learning, the researchers discovered that a shared depiction may function as a form of group memory by reflecting previously discovered information or concepts upon which students could draw inspiration and expand. Students were invited to work together to create a concept map by Roth and Roychoudhury [208], who reported similar results to Suthers. The protocols that Roth and Roychoudhury detailed serve as an illustration of how mind mapping might improve the process of meaning negotiation. Students frequently engaged in conversation regarding the nature of the connection between two ideas as they worked on the construction of a concept map. These observations have also been reported by Jamil et al. [113] within an investigation of collaborative work around digital table tops, in addition to specific physical behaviours emerging within that study.

Students' ability to acquire conceptual knowledge can be positively impacted by engaging in collaborative conversation about concepts. Kwon and Cifuentes [133] revealed that an individual concept-mapping activity and a collaborative concept-mapping activity displayed comparable effects on a traditional test of knowledge. This was discovered by comparing the learning effects of the two different types of concept-mapping activities. However, the quality of the mind maps produced by students who developed the maps in a group setting was noticeably higher. Kwon and Cifuentes suggested that the sharing of knowledge and ideas among students and the verbalisation of those ideas helped students better understand the interrelationships between different concepts.

To effectively complete an inquiry-based collaborative learning work, students must reach a broad agreement on the learning assignment [269]. Because students need to reach a consensus on the ideas and concepts that they desired to include in their maps, the production of a shared representation of the domain generates the requirement for consensus-building activities [211]. According to Damsa et al.

[57], making students feel as though they have a shared responsibility for a representation might encourage them to investigate one another's points of view and ideas, and in certain cases interrogate and critique them.

3.4.2 VR-mediated Mind mapping

VR-based educational applications are not new. They are commonly used to simulate real-world tasks, like clinical protocols [73, 209], using specialised environments. In engineering, research has demonstrated how Building Information Modelling and evacuation planning can be facilitated by VR [102] and VR applications like Construct3D [121] allow students to experiment with their own ideas. These domain-specific applications have their benefits, but they are not generalisable to other subject areas without significant modifications. A subject-agnostic VR application which scaffolds reflective exploration of any topic can support pan-disciplinary learning activities.

VR presents a unique opportunity for mind mapping exercises as it can inherently support spatial organisation of information in 3D. VR can also support interesting interactions and collaboration, acting as a 'one-world multiple-perspectives' environment for exploration of concepts. As a learning tool in the classroom, it provides unique opportunities for the educator to direct and shape the conversation around a pre-determined set of keywords while allowing unique behaviours and interaction strategies to emerge among the learners.

Mind mapping is an excellent candidate as it is domain agnostic. It also adapts easily to the VR-medium as it is an information organisation activity and VR provides an interactive 3D environment for spatial organisation of virtual content. The use of virtual 3D collaboration spaces is known to help with spatial organisation of information [25]. Other reasearch [12] has shown that virtual environments can assist students in visualising abstract concepts and complex visual relationships mediated through other related immersive technologies such as Augmented Reality (AR). Mind mapping in AR has been shown to improve cognitive functions [89] and enhance classroom interactivity, students' divergent thinking and stimulate students' learning interest [279]. However, VR-based mind mapping is less understood as an activity itself since very few commercial examples [48, 262] are available. Studies have looked at the interaction schemes required for usable mind mapping in VR [164, 238] but there is a gap in the literature when considering behaviours and strategies. There is a need to explore if VR as a meditating technology reveals cognitive affordances of mind mapping which are suppressed, unsupported or unreported in other mediums. With this study, this gap in understanding is addressed by investigating if VR is transformative enough to support unique behaviours and allow new strategies for reflection to emerge.

Digital implementations of mind mapping are criticised for being slower than traditional pen and paper mind mapping, often turning into an exercise in tool management, rather than spending time on the actual core mind mapping activity itself [44]. The challenge for VR is to identify efficient and intuitive ways of using VR concepts to create mind maps. VR based mind mapping is less understood and very few examples [48] are available. The open question is how to converge the existing concepts of VR-based interaction into a fluid interaction experience such that the focus of the user is on the reflection and abstract thinking arising from mind mapping rather than wielding of the tools to operate within the VR environment.

3.5 Conclusion

When addressing the application of virtual reality technology, the term immersion can have multiple unique connotations. This chapter uncovered several examples of incompatible usage of this phrase, which was widely utilised in respect of non-immersive technology, when conducting a literature review. Non-immersive technologies like 360-degree videos, CAVE and non-headset based VR (desktop VR or browser-based) were discarded in favour of immersive technologies like Oculus GO, Samsung Gear, HTC Vive, Samsung Odyssey, and Google Cardboard. Unhappily, the public's comprehension of the many immersive technologies is still marred by confusion and inconsistency used throughout the industry.

In the body of VR research that included learning theories, several distinct types of research were found. Firstly, some articles detailing VR applications in an educational context failed to include definitive pedagogy as the basis for their theoretical framework. While most of these articles provided a comprehensive description of the development of VR applications, they concentrated primarily on the applications' usefulness. Because of this, the works that were presented had an experimental quality and could only be replicated to a limited extent; they could not be considered generalisable. Secondly, there was frequently a gap between the information presented in the articles that detailed the evolution of VR and those that referenced various learning theories. For instance, the authors did not examine the learning results of the application; rather, they simply evaluated its features and its usability. Thirdly, there were several papers that focused on the fundamental educational design theories for VR but lacked discussion on the technological advancements. As a consequence of this, it was frequently challenging to separate various aspects of design from these articles.

This availability of prior research indicates an increasing interest in the application of VR technology across a range of professions including computer science and engineering. However, this perception must be tempered, as it was difficult to find research that discussed topic agnostic experiences or lessons learned from the deployment of VR in actual college or university courses. The vast majority of the research either reported on the design process or investigated possible topic specific applications of VR-based education.

It appears that VR has reached a level of maturity where it could be utilised effectively to instruct declarative, practical, and procedural information. Some examples are the prevention of fires, surgical procedures, astronomy, and nursing. In these instances, professional VR applications were utilised, and it was demonstrated that these applications are suitable for education. In spite of this, a number of articles suggest that VR for educational purposes is still in the testing and prototyping stage, however some conclusions on the desired application for VR in educations can be made. The ability to deliver an immersive learning environment is one of the primary advantages of VR. From the literature, it appears that VR enables students to explore and interact with virtual environments in a manner not possible with conventional teaching methods. Participating actively in the learning process, as opposed to passively receiving knowledge, can make the learning experience more engaging and memorable. The capacity to build accurate simulations of real-world settings is another advantage of VR. This allows students to practise and apply their new skills and knowledge in a safe and supervised setting. This is especially valuable for fields such as medicine, engineering, and architecture where hands-on teaching can be difficult or even dangerous. The one design component that is consistent across all VR educational research is the presence of fundamental interactions. Authors draw attention to two distinct degrees of engagement with the user, namely interactions that take place within a VR environment, and interactions with the hardware itself, i.e., the usage of haptic and sensor technology in the headset and/or controllers that exist to connect users the VR environment.

As a more engaging and immersive learning medium, VR may help boost student engagement and motivation. This might be advantageous for students who have trouble concentrating or remembering material in a regular classroom setting. This also feeds into VR being an accessible technology, providing students who have specific learning needs with additional means of accessing and interacting with material. It may also be utilised to give remote learning experiences, which can be especially valuable during times of social distance or when students cannot attend a real classroom. VR may also be utilised to improve students' creativity and problem-solving abilities, since it enables students to construct engaging and innovative learning experiences. Moreover, as the price of VR gear decreases, it becomes more affordable and accessible, allowing it to be utilised to create learning experiences for a broader spectrum of students, including those who may not be able to attend certain forms of physical training.

Only a small number of articles investigated the learning outcomes that were achieved by deploying VR in a particular field, and the majority of the evaluations that were conducted focused on the usability of the system. This is also another measure that suggests the maturity of VR within education still has room for improvement in terms of integration, accessibility, and effectiveness in educational settings.

Chapter 4

Opportunities and Challenges for VR within Education

Over the past two decades, the education sector has seen significant change with respect to technology. Change has centred around the use of the Internet and devices and application in the classroom, including smart phones, tablets and modern computers. As these technologies continue to evolve, they become more pervasive and influential in our lives, bridging the gap between workplaces, education, and the home. The Internet of Things (IoT), Robotics, Artificial Intelligence (AI), Virtual Reality (VR) and Augmented Reality (AR) constitute the bulk of the latest advances. As more educational institutions seek to adapt to these developing technologies, many have struggled to acquire the skills and knowledge to enable them to update their existing educational practices. This difficulty can be split into two main factors. The first issue is structural and is attributed to the failure of institutions to fund the investment necessary to acquire digital resources, including software and hardware technologies. Institutions are also resistant to retire existing hardware and software, which they may consider perfectly serviceable, to make way for new technology. The second issue considers educators' inability to conceptualise how new technology might be used in their practice and how to modify existing resources and apply the new technology in meeting the ever-changing requirements of students.

Resource creation is a time-consuming task, and it is not always immediately obvious how to populate these platforms with the high-quality resources that both institutions and students have come to expect. Many platforms require specific training, and this has become even more apparent with the advent of immersive technologies such as VR and AR. The key to using these technologies effectively is high quality educational content that leverages all the benefits that these technologies offer, for which there is a need to identify the tools required by educators to do this.

This chapter, through surveys and interviews with practicing educators, aims to understand the challenges of educational resource creation and its relation to the wider adoption of VR technologies within education. As the first study investigating this combination of resource creation and VR, it is positioned as exploratory in nature, with the results determining the potential scope for further investigations.

4.1 Motivation

The aim of this study was to explore the factors which affect VR adoption by educators, particularly those factors relating to resource creation.

We focus predominantly on educators' perception of VR utility, rather than benefits to students since this is well covered in previous research. Due to identifying a gap in the literature, the primary concern is the creation, re-use, and modification of educational resources for VR activities. By way of a survey and semi-structured interviews, we sought opinions and attitudes towards these factors while also collecting information on what kind of activities educators would use VR for. As an exploratory study into a new area, this research is intended to provide a baseline understanding of the issues facing educators for these specific factors, thus informing future research and design of VR educational applications and platforms.

4.2 Methodology

4.2.1 Participants

Interview volunteers were pre-screened so that only those educators who actively use technology in their teaching were selected as participants. Pre-screening interview volunteers to include only educators who actively use technology in their teaching ensured focus on garnering relevant and expert insights. Such educators are likely to provide detailed and nuanced information about the practical use, challenges, and benefits of technology in education, aligning closely with the research objectives that aim to understand technology's application and impact. Their experiences offer valuable data for benchmarking best practices and understanding barriers to technology adoption. This approach ensures that the research is informed by practical, firsthand experiences, leading to richer, more meaningful findings and contributing to the development of effective guidelines for technology integration in educational settings. From these participants, five interviewees were selected, representing primary, secondary, FE and HE education within the UK.

A Qualtrics survey (see appendix B.1) was distributed among education networks (such as the ILRN Discord channel and the researchers pre-existing professional network) to ensure that only those with teaching responsibilities completed the survey. Completion of the survey entitled the participant to be entered into a raffle for a £20 Amazon gift voucher.

4.2.2 Demographics

Demographic data were collected as part of the survey to understand the background of the respondents. This included information such as age, gender, educational background, and teaching experience. While not all demographic data were directly used in the analysis, they provided context to the survey responses and helped in interpreting the results more comprehensively. The demographic data also aided in assessing the representativeness of the sample and in understanding the diversity of perspectives in the study.

35 respondents identified as male, 25 female and one preferred not to say. 31 respondents taught at primary level, 13 at secondary, 7 at FE (Further Education), 8 at HE (Higher Education) and 7 in a non-academic setting (i.e., workplace training). The cumulative total is higher than 61 as some taught at multiple levels (i.e., FE+HE). Geographically, 28 respondents were from the UK, 4 from Europe (not including UK), 23 from North America, 3 from Central America and 3 from South America. 56 respondents held a formal teaching qualification, 5 did not. Only those from the UK were what kind of teaching qualification they held. Degree with QTS (Qualified Teacher Status) was the most frequent with 11, 4 each for PGCE in post compulsory (age 14+) and Fellowship of the Higher Education academy, and 3 for PGCE (Post Graduate Certificate in

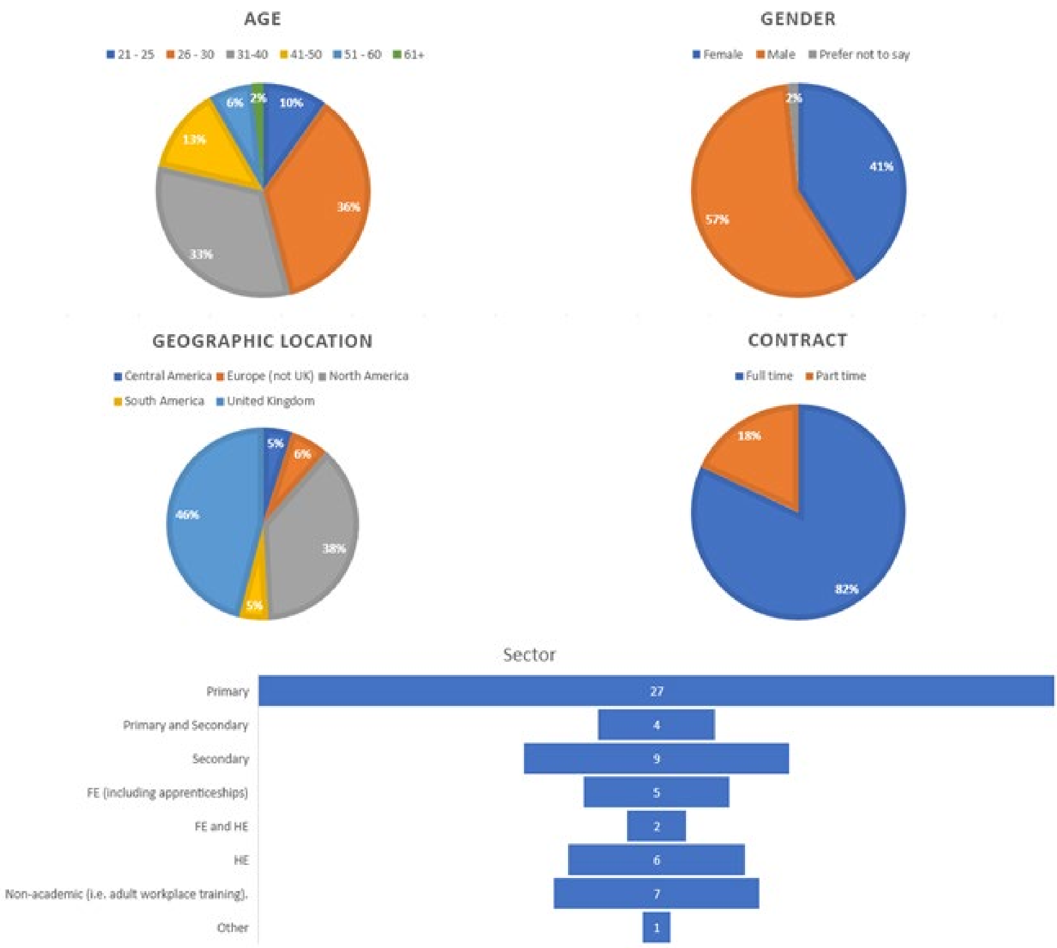


Figure 4.1 Demographic data for Surveys and Interviews

Education) with QTS. 50 respondents stated they taught full time with the remainder part time. 46 respondents stated they had some management responsibilities and 15 that they did not. Of those with management responsibilities, 23 were a subject lead and 13 department lead and the remainder spread across the remaining categories at 2 (+/-2). Subjects taught among respondents were English, Art (including music, fashion etc.) and Computer Science at 8 respondents each, 5 for mathematics, 4 for Foreign Languages and Geography, 3 for Science (Physics, Chemistry and Biology) with the remainder spread across the other subjects. Some of this demographic data is visualised in figure 4.1.

4.2.3 Surveys and Interviews

In the development of the survey and interview instruments for this study, a rigorous and systematic approach was employed. The formulation of survey questions was informed by an extensive review of existing literature in the field of VR in education. This review helped in identifying under-explored areas, especially concerning the challenges faced by educators in creating VR resources. Additionally, consultations with educational technology experts were conducted, which influenced the shaping of the survey questions.

The survey was designed with questions that were clear, concise, and directly related to the experiences of educators with VR technology in resource creation. A mix of quantitative and qualitative questions was included to gather a broad spectrum of data. Open-ended questions were also incorporated to allow respondents the opportunity to provide in-depth insights and personal experiences.

Similarly, the development of the interview instrument involved the creation of a set of semi-structured questions. These were designed to be flexible enough to facilitate in-depth discussions yet focused to keep the conversation aligned with the research objectives. The refinement of these questions was achieved through a pilot study with a group of educators experienced in using VR in teaching. Their feedback played a crucial role in fine-tuning the questions, ensuring understandability and relevance to the study participants.

Ethical considerations were central in the formulation of both survey and interview questions. Steps were taken to ensure that all questions respected the participants' privacy and professional boundaries. The final version of the instruments was reviewed by the institution's ethics committee, ensuring compliance with ethical research standards.

By adopting a comprehensive and iterative approach in the development of the survey and interview instruments, robust, relevant, and insightful data were ensured, providing a solid foundation for the analysis presented in this chapter.

4.2.4 Interview Strategy

Participants were interviewed in a semi-structured manner, using the survey as a guideline for questions. Interview participants were guided through the survey so that comparable demographic data could be collected among the survey respondents and interviewees. Where responses mandated an open-ended answer, these were given verbally to the interviewee and the interviewer elicited further responses where required. This allowed for more verbose and in-depth survey responses, illustrated by the average survey response time of 20 minutes versus 45 minutes for the interviews. All interviews were audio recorded with permission from the participants. All interviews were conducted in English.

In qualitative research, interviews are a mechanism that attempts to understand the world from the participants' perspective, to decipher the significance of people's experiences, and to reveal their lived reality prior to scientific explanations [251]. Cohen et al. [49] state semi-structured interviews provide the opportunity to study the participant's thoughts, emotions, and attitudes regarding a particular topic and to delve deeply into personal methods. Semi-structured interviews is a versatile approach to conducting research on a limited scale [66] and tends to provide more meaningful data when the sampling is small. Semi-structured interviews also permit thematic examination of qualitative data [9].

The foundation of semi-structured interviews is their adaptability, enabling the interviewer to investigate conversation topics organically as opposed to anticipating them. In contrast to exact questions, informal semi-structured interviews may start with a broad, overarching subject and then expand out into subtopics [11]. This methodology gives the interviewee the freedom and versatility to choose what needed to be said, the level explanation to provide, and the amount of specificity to deliver.

There may be disadvantages to semi-structured interviews, however. For example, A researchers own bias may become evident in the gathered data if they steer the discussion in a certain direction based on their personal opinions or interests. In addition, there is a potential of social desirability bias, in which individuals provide answers they believe to be appropriate or expected as opposed to providing accurate or genuine replies. Lastly, semi-structured interviews may be resource intensive and time-consuming owing to the substantial planning and preparation necessary to guarantee that the questions are acceptable and relevant to the study themes.

Mitigation efforts were applied to assure the accuracy and rigour of the data acquired via semi-structured interviews to reduce such possible dangers. The study team assessed the interview questions to ensure they were suitable and relevant and included a pilot study to test and refine the questions [189]. In addition, the interviewers completed appropriate training and worked through exercise to develop their expertise in qualitative research methodologies including the ability to develop rapport with the participants [224]. To confirm the validity and trustworthiness of the results, the data acquired via semi-structured interviews was triangulated against data collected obtained via other approaches, such as surveys and document analysis [60].

Despite the possible downsides, semi-structured interviews were deemed a valid method of data collection for this research since they enabled participants to describe their experiences in their own terms and investigate the subject in detail. To lessen the risks, the interview questions were carefully linked with the research themes and candid responses were encouraged. To ensure the validity and reliability of the results, semi-structured interview data was triangulated with data acquired via other methods, including surveys and document analysis.

4.2.5 Analysis

The statistical analysis of the survey data was performed using a combination of tools including IBM SPSS 26 and Microsoft Excel. Descriptive statistics were employed to summarize the demographic data, including frequency counts, percentages, means, and standard deviations. For inferential analysis, appropriate statistical tests such as chi-square tests for categorical data and t-tests for continuous data were applied to determine significant differences and relationships between variables. Additionally, correlation analysis was conducted to explore the relationships between different aspects of educators' experiences with VR. The choice of statistical methods was guided by the nature of the data collected and the specific research questions being addressed. Interview recordings were auto transcribed using Otter.ai then manually checked and refined for accuracy. 213 quotes were identified during initial coding of the transcribed interviews with 31 themes identified via a deductive approach. For the themes, these were further analysed using inductive thematic analysis [34], resulting in 5 major themes identified. Thematic analysis is a technique for detecting, analysing, and reporting qualitative data patterns or themes. It entails a methodical and rigorous process of discovering patterns within the data, followed by the organisation of these patterns into overarching themes. Thematic analysis is a versatile technique that may be used to a variety of data types and theoretical and epistemological viewpoints. This technique aided the discovery of recurrent patterns and themes associated with the study subject inside the dataset. The thematic analysis process consisted of following the seven steps outlined by Braun and Clarke, which included the transcription of the interviews, becoming familiar with the data by reading and reviewing it, coding the data to identify initial patterns and themes, searching for themes across the data, reviewing and refining the identified themes, naming the final themes, and concluding the analysis.

The interviews were first transcribed to provide a written record of the data. The researchers then read and acquainted themselves with the data. Then, they began coding the data, which consisted of meticulously finding important passages of text and assigning them a label, or code, that encapsulated the core of the data. After completing the coding process, the researchers continued their search for themes. This entailed putting relevant codes together and organising them into bigger topics. The researchers then examined the themes, ensuring that they correctly reflected the data and improving them as required. After identifying the themes, the researchers classified and categorised them, generating clear and succinct explanations of each topic. The analysis was completed, and the themes were used to form conclusions on the study problem. During the procedure, the researchers maintained a reflexive approach, regularly evaluating and reflecting on their assumptions, biases, and interpretations to ensure the validity and dependability of the study. The use of Braun and Clarke's methodology to thematic analysis provides a rigorous and methodical method for analysing the data, resulting in an in-depth comprehension of the study subject.

To ensure reliability, the primary researcher conducted analysis in concert with two additional researchers unrelated to the research and no involvement with conducting the interviews or initial transcription. The primary researcher's native language was English as was one of the additional researchers, with the remaining researcher having Dutch as a primary language but with a high level on English fluency. For each theme, each researcher initially clustered one third of the quotes. The researchers then discussed each cluster until consensus was reached upon the correct make up of each cluster which were then finalised for further analysis and from which the results of the study could be derived. Additional analysis of the survey responses was carried out by the researchers, following a similar thematic analysis that was used to validate and triangulate the interview quotes and arising themes.

4.3 Results

Initially, 74 survey responses were recorded. After data cleansing on the completed surveys, there were 61 valid surveys to analyse. Data cleansing included removing all surveys completed faster than 7 minutes, accounting for random click through just so the participant could be entered into the raffle and removing survey responses that contained nonsense responses to important questions (i.e., survey questions VR1, VR2, VR4 and VR6) for the same reason.

4.3.1 Resource Creation

- Respondents reported a mean of 6.46 hours allocated for resource creation (from scratch), with a standard deviation (SD) of 4.59 hours.
- The actual time spent on creating resources was a mean of 8.87 hours (SD = 4.81), a 25% increase over the allocated time. One interviewee remarked "*it's annoyingly high.*"
- Common types of resources created: lesson plans (30 respondents), Slideshows/Presentations (29), worksheets (20), syllabus (20), tutorials/'how to' guides/instruction manuals (19), online quizzes (18), online learning pages (e.g., Moodle) (17), illustrations/diagrams (16).
- 45 respondents collaborated with other educators in resource creation, while 16 did not. Frequency of collaboration: more than once a week (17

respondents), once every two weeks (12), once a month (9). Reasons for collaboration included sharing resources and mutual support.

- Reasons for not collaborating: mismatched planning times with colleagues (14 respondents), lack of time (10), not required (8).
- Respondents spent a mean of 4.89 hours (SD = 3.53) sourcing resources within their organisation, typically schemes of work, lesson plans, and syllabuses.
- 36 respondents sourced resources from external providers, while 25 did not. Average time spent sourcing external resources: 3.92 hours per week (SD = 3.49). Main sources included TES.co.uk, EEF, and White Rose. 25 modified these resources, mainly in minor ways, while 11 did not.
- Tools used for creating resources from scratch: standard productivity tools like Office (16 respondents, with Word (11) and PowerPoint (7) being most common), a mix of standard and enhanced productivity tools and online tools (11), predominantly online tools (5), mainly enhanced productivity tools (3).

- 12 survey responses indicated challenges in conceiving how to build VR resources and integrate them into a virtual learning environment. These challenges were also reflected in interview responses, with further discussion in section 4.3.3.

4.3.2 Virtual Reality

- Plutchik's emotion wheel was used to measure respondents' attitudes towards VR adoption, coding each response with a positive or negative value on a scale from -3 to +3.

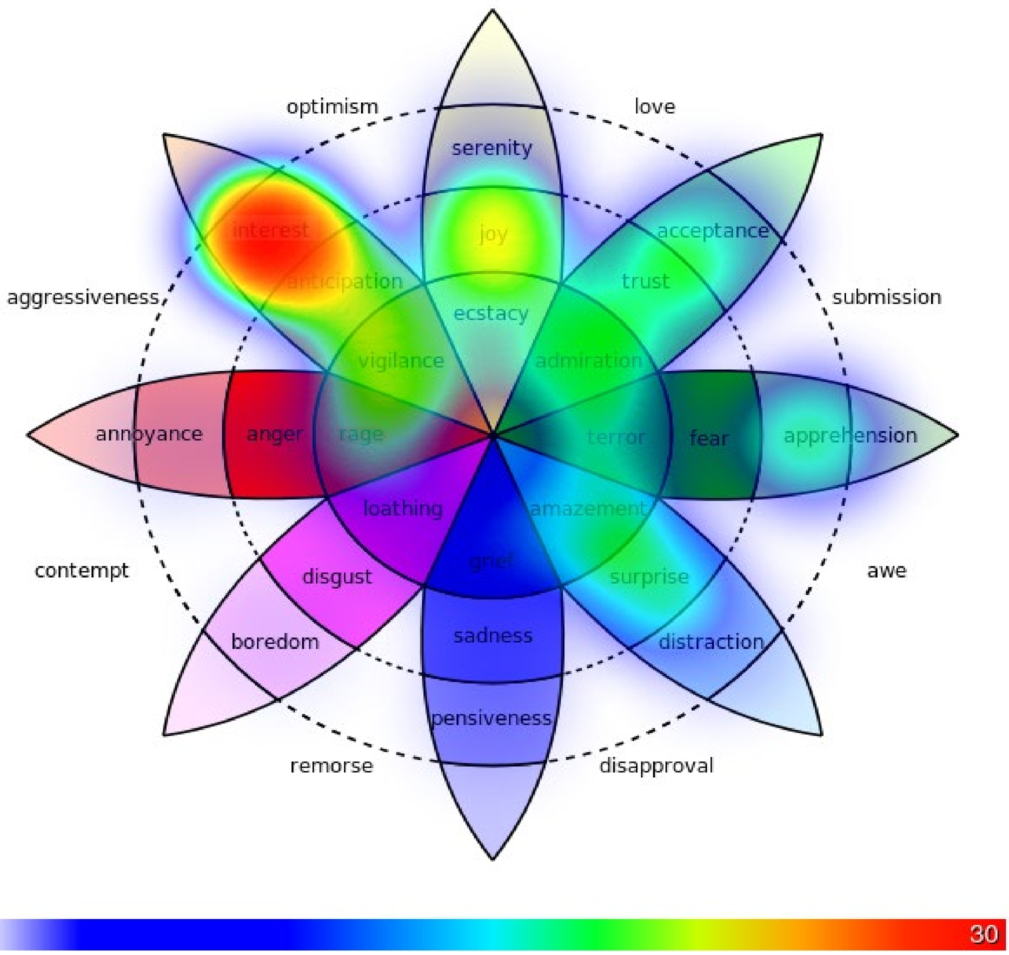


Figure 4.2 Plutchik responses

Respondents were asked to select their top three feelings when being asked to teach with VR.

- The average Plutchik coded score was 2.25 (SD = 2.78), indicating a generally positive emotional response towards introducing VR in practice.
- Significant positive responses included interest (30 respondents), joy (16), and anticipation (14), with apprehension (13) being the most common negative response.

The detailed results are presented in Figure 4.2.

- Respondents identified various educational benefits of VR, noting its immersive nature and the fun and stimulating aspects of VR activities.
- They recognised VR's potential to provide experiences in environments normally inaccessible, like space and significant global locations.
- When asked about the types of educational activities for which they would use VR, the majority chose simulations (35 respondents).
- Other popular responses included games and cooperative games (21 and 20 respondents respectively), and thought exercises like brainstorming (18), mind mapping (15), and concept mapping (14).

The detailed results of these responses are shown in Figure 4.3.

4.3.3 Themes

Five main themes recurred across most participants.

4.3.3.1 Conceptualisation of VR resources and world building

The responses provided by respondents to the VR10 'Thinking about the tools you currently use, can you describe the (existing or new) process you might follow to populate these VR activities with your chosen resources?' question highlight several concerns and challenges that educators face when considering the development and integration of VR content into their teaching practices. These concerns demonstrate that educators currently may not know how to or cannot

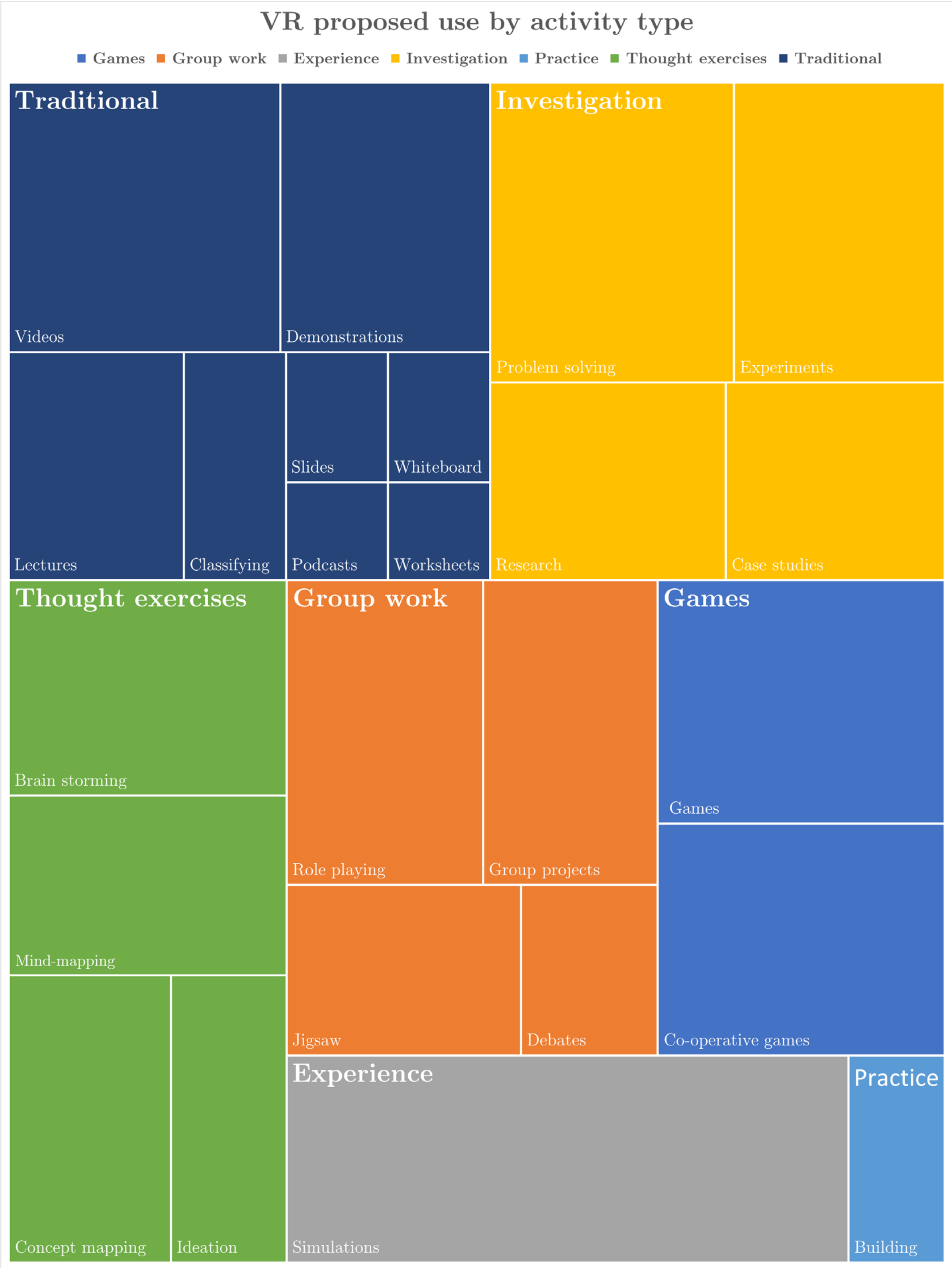


Figure 4.3 Intended educational activities.

even conceptualise how to create content for VR and build virtual worlds that support learning and can be categorised and explained as follows:

- Lack of Technical Knowledge: Educators expressed concerns about their ability to develop VR content, with statements like *"I don't feel I would* *be able to do this*" and "*I wouldn't have a working knowledge of how to transfer my current resources into VR.*"

- Difficulty in Envisioning VR Implementation: Responses such as "It would be difficult to imagine until I can see it working and what tools would be available" indicate challenges in conceptualising how VR would work in practice.
- Limited Institutional Support and Resources: Comments like "*I haven't given it much thought... as it's not something the Institution is actively looking at*" and "*we're just getting started on online learning via Zoom, so VR would be a light year step ahead again*" suggest a lack of prioritisation of VR in some educational institutions.
- Uncertainty About Where to Start: Educators voiced uncertainty about initiating VR content creation, with responses like "*Never made VR resources so wouldn't know where to begin*" and "*I don't know enough about VR activities to answer this question.*"
- Incompatibility with Current Teaching Practices: Statements such as "*It's like what I'm good at doesn't apply to VR*" reflect concerns about the applicability of existing teaching skills and methods in VR environments.
- Need for a Different Mindset and Approach: The response "*We need to approach XR with a different mindset*" highlights the recognition that VR requires new teaching strategies and a shift in thinking.
- Challenges in Content Adaptation: Statements like "Will need to replan the delivery around VR" and "*What I have taught is still a little difficult to translate into VR*" indicate difficulties in adapting current teaching materials to VR.
- Lack of Existing Tools to Support VR Content: Responses such as "*I don't think there's any tools that I currently use that would translate*" point to a need for tools specifically designed for VR content creation.
- Desire for Access to Existing VR Resources: Interviewees expressed a preference for using existing VR resources for inspiration, with comments like "*if I use VR a bit more, then I might have an idea of how or why or at least what resources would be appropriate for it.*"

Preference for Well-Curated Repositories of VR Resources: Educators showed a strong interest in having access to repositories of high-quality VR educational resources, as indicated by statements like "*some kind of repository of common resources*" and inquiries about the availability of such resources. These responses collectively demonstrate that educators may face various challenges and uncertainties when it comes to creating and implementing VR content in their teaching practices. These challenges include technical knowledge gaps, difficulty in conceptualising VR implementation, limited institutional support, uncertainty about where to start, potential incompatibility with existing teaching methods, and the need for a different mindset and approach to teaching with VR.

4.3.3.2 Educational benefit

The responses especially to question VR6 question displayed that educators have wide and varied ideas on how using VR in their practice might benefit students. These ideas can be grouped into several categories:

- Access to otherwise inaccessible experiences: Responses like "*Experience of visiting places that would otherwise not be possible*, "*See and touch where cost or safety of materials might be prohibitive*" and "*As a school in the top 10% disadvantaged areas in the country, VR could provide our children with experiences that they potentially could never experience first-hand*" indicate that educators see VR as a way to expose students to experiences that would be otherwise unavailable to them due to physical, financial, or safety constraints.
- Enhanced visualisation and manipulation: Statements such as "*Far greater ability to show the creation of complex items and allow the students to manipulate them in 3D space*" and "*Allows for extending reality beyond physical limits*" show that educators believe VR can help students better visualise and manipulate complex objects, concepts, or situations, enhancing their understanding.
- Increased engagement and motivation: Responses like "*It would make learning fun and could provide a great hook to lessons*", "*Stimulate students' interest in learning and enliven the classroom atmosphere*" and

"*Children have more fun learning and are more interested in learning*" suggest that educators view VR as a means to make learning more engaging, enjoyable, and motivating for students. These responses were closely related to immersive learning experiences. Statements such as "*Immersive experiences for students*" and "*In my opinion, VR can better arouse students' interest in learning and reduce the boredom in learning*" emphasise that educators consider VR as a tool to create immersive learning environments that promote students' interest and reduce boredom.

- Interactivity and active learning: Statements like "*Allows students to be involved. Interactive*" and "*Turn their passive learning into active learning*" suggest that educators view VR as a way to promote interactivity and active learning, where students take a more active role in their learning process.
- Enhanced understanding and cognition: Statements such as "*Let students more accurate understanding of relevance, better cognition*" and "*You can make some abstract problems in realisation, it's easier to understand*" indicate that educators believe VR can help students better understand complex or abstract concepts by making them more tangible and experiential.

However, interviewees felt that VR providers (i.e., application developers and hardware vendors) did a poor job of conveying the benefits of VR for students. It was felt this harmed the potential for VR to be adopted with responses such as "*concerns from a teaching perspective would be ensuring that it was actually benefiting the student experience*", "*how does everything get incorporated together so that VR is, is a supplement that makes a lesson better collectively*", "what would be the benefits to the student". Inclusivity also appeared to be a concern with some responses such as "*or is only benefiting for certain students*". Respondents indicated they would like to see evidence-based research to justify using new technologies such as VR.

With these responses from surveys and interviews, it is demonstrated that educators see a wide range of potential benefits in using VR in their teaching practice, including providing otherwise inaccessible experiences, enhancing visualisation and manipulation, increasing engagement and motivation, offering safe environments for trial and error, promoting immersive learning experiences, encouraging interactivity and active learning, and improving understanding and cognition.

4.3.3.3 Engagement

- Engagement and Creativity in VR:
  - Interviewees discussed engagement along with creativity.
  - Quotes include: "*that would be as engaging as seeing performance in action*", "*VR might allow that to be done more safely and problem solving as well could be something that would really engage children*".
- Immersion in VR Learning:
  - Survey responses emphasised the immersive aspect of VR.
  - Quotes: "*immersive learning, bringing subjects to life and interacting with situations that would otherwise be impossible*", "*Can let the student be more [sic] immersive learning, strengthen the learning effect*".
- Connection between Engagement and Immersion:
  - Engagement and immersive learning frequently mentioned together.
  - Note: Respondents had difficulty articulating their understanding of engagement when probed in interviews.

4.3.3.4 Classroom Management

- Behaviour and Classroom Management as Barriers:
  - Respondents identified behaviour and classroom management challenges when integrating VR.
  - Concerns about managing both physical classroom space and VR learning environment.
  - Quotes: "*I'd be concerned about behaviour*", "*if you try it, but then it creates some behavioural problems that we couldn't deal with*", "*I think behaviour as well*".

- Need for Additional Research and Policy Updates:
    - Suggestions for more research on behaviour management specific to VR use.
    - Recommendations for updating institutional behaviour policies to accommodate VR technology.

4.3.3.5 Multi-modal learning

- Multi-Modal Learning and VR:
    - Interviewees frequently discussed multi-modal learning benefits of VR.
    - Common statement: "you can deal with all the students' senses".
- Breaking Classroom Boundaries:
    - VR viewed as a tool to transcend traditional classroom limitations.
    - Quote: "*it gets students out of the ~ four walls of the classroom*".
- Use of Physical Proxies in VR:
    - Discussion about using tangible objects like musical instruments and stage props in VR.
    - Quotes: "*kids just loved the idea of being able to see and be able to play these instruments and stuff*", "*So you've got a virtual stage, and you can, you know, set people up in the right places even things like more technical stuff, like light control and stuff like that*".
- Institutional Policy Barriers:
    - Institutions' policies identified as obstacles for adopting technologies that promote multi-modal teaching.
    - Examples include blanket bans on mobile phones: "*Massively against mobile phones being available*".
    - Concerns that VR might face similar restrictions despite potential benefits.

4.4 Discussion

An obvious discussion point is that educators spend more time creating resources than the time they are allocated, with the mean almost 9 hours a week spent on resource creation. This is nearly a quarter of a regular 42 hour working week. It is disappointing that despite attempts in the sector to reduce teacher workload these types of issues persist. Although clearly a concern among educators, it was decided not to delve too deeply into this issue at it appears to be an organisation and workforce management problem to solve. Despite this, well designed tools and curated content could go some way to alleviating time pressures that educators face.

36 respondents (59%) stated they sourced resources from external organisations. This indicates that despite many repositories of resources existing, it is difficult to find resources or that the resources do not match educators' requirements. This has an obvious impact of increasing the time educators spend on creating their own resources from scratch. This was corroborated by the responses provided when asked what sources they use with only TES appearing in significant numbers, again indicating there doesn't appear to be a universal central repository of resources for educators that is frequently used. This has repercussions when considering the consistency of resources used across education.

It was encouraging to observe the overwhelmingly positive Plutchik responses to VR being introduced in the respondent's educational practice, indicating that educators are excited and open to the possibilities VR can bring to education. There were a small number of negative responses, however most of the negative emotions can be addressed, as illustrated through the interview responses that mention training, management support and comprehensive reasoning of how VR might benefit students and education. Furthermore, the slight negative Plutchik responses seem also in part related to behaviour and classroom management concerns. Designers of VR applications need to think carefully about how educators need to manage both the physical and virtual learning spaces simultaneously. One possible solution would be to consider an Augmented Reality based 'window into the world'. This is an area ripe for future research. Respondents were able to identify a range of benefits that VR might bring to education, and these were mostly in line with the existing research. However, they were unable to articulate their understanding of the term 'engagement'. There appears to be an assumption, and this is also evident in the existing literature, that educational VR activities will automatically be more engaging within an educational context than existing activities. It appears this is a flawed assumption to make and requires validation.

The wide range of activities that educators stated they would use VR for is encouraging. It demonstrates, especially when combined with the emotional response to its introduction, a willingness to adopt the technology. While simulation activities might be an obvious and expected use case for VR, thought exercises was an unexpected outcome. While simulations tend to be domain specific, such as medical simulation etc., thought exercises tend to be domain agnostic and can cover a wider area of curriculum. Indeed, research into mind mapping in VR is already ongoing [237] and it is encouraging that educators can see the potential for VR in this area. As pedagogy continues to move away from the once fashionable VARK model [80], where it was once thought that students had one preferred learning style, educators have come to realise that multi-modal delivery is best placed to leverage these learning styles [119]. As illustrated in the interview responses, this is also demonstrated by the participants whom frequently posited that VR was a potential tool to support this multi-modal approach.

The final point to address in this study is how respondents struggled to conceive how they would populate VR worlds with appropriate educational resources. Current state of art VR development is generally not fit for purpose to be used directly by educators given the amount of specialist knowledge needed to build basic content. The time required is proportional to how complex the development tools are for content creation. Critics may argue that bespoke applications may be the solution, but they are a stop gap for more generalisable, topic agnostic environments. Bespoke applications do not allow customisations that allow educators to leverage VR for a wider range of topics and encompass true multi-modal teaching. The challenges educators face in implementing Virtual Reality (VR) in their teaching practices can be summarised as follows: lack of technical knowledge hinders their ability to develop and adapt resources for VR; difficulty in envisioning VR implementation and the necessary tools for effective experiences; limited institutional support and resources, which restricts opportunities to develop VR content; incompatibility with current teaching practices, making adaptation difficult; challenges in content adaptation, as translating existing materials and methods into VR activities proves difficult; and a lack of existing tools and resources for VR content creation and world building. Educators prefer well curated repositories of high-quality resources over creating their own, indicating a need for more accessible VR content to inspire and support their practice.

4.5 Conclusion

This exploratory study has shed light on several key aspects related to RQ2, RQ2.1, RQ2.2, and RQ2.3, which revolve around the factors influencing the creation, organisation, and delivery of VR content in education. The findings reveal that educators are enthusiastic about the potential of VR in education but require more clarity about its tangible benefits, addressing RQ2, which focuses on the key factors in VR content creation and delivery.

Regarding RQ2.1, which pertains to educators' desired uses of VR in their pedagogy, the study highlights a broad range of potential VR applications imagined by educators. This includes not only domain-specific simulations but also domain-agnostic thought exercises. The educators' readiness to adopt VR, coupled with their diverse ideas for its application, underscores the need for VR tools that are adaptable across various educational scenarios.

Concerning RQ2.2, which enquires about the barriers to VR implementation, the study identifies several challenges. These include educators' lack of technical knowledge, difficulty in envisioning VR implementation, limited institutional support, and the time and skill required to develop VR content. This finding is crucial as it pinpoints the specific hurdles that educators face in incorporating VR into their teaching practices.

Finally, addressing RQ2.3, which questions the tools or processes needed for effective VR use by educators, the study suggests the necessity for user-friendly, domain-agnostic VR applications. Educators show a preference for well-curated resource repositories and tools that simplify the creation of VR content. Therefore, developing such tools and repositories would significantly aid educators in integrating VR into their teaching, thus answering RQ2.3.

In summary, this study indicates that while there is significant excitement and potential for VR in education, there are also notable challenges and misconceptions. To maximize the benefits of VR in educational settings, it is recommended that education leaders not underestimate the resources required for its implementation. Additionally, there is a need for developers to create versatile, domain-agnostic VR applications and for institutions to provide adequate support and clarification on the educational benefits of VR. These actions will help educators effectively integrate VR into their teaching, ensuring that the technology is used as a complementary tool rather than as a replacement for traditional educational methods.

Chapter 5

LOGIBOT: Engagement Through Virtual Reality

5.1 Introduction

In the previous chapter, the potential and problems of using VR in education was examined from the perspective of educators. Educators were surveyed, asking their experiences using virtual reality in the classroom and discovered that while there are significant opportunities for engagement and improved learning outcomes, there are also obstacles such as cost, technical difficulties, and a lack of training and support for educators. The research indicated that despite the promise for VR to improve student engagement and learning results, educators must carefully assess the integration of VR technology and get proper training and assistance to overcome its use barriers.

This new study was designed to address two specific findings of the above research. Firstly, it identified the need for further research to validate the assumption that VR automatically increases engagement in an educational context. This is further compounded by respondents not being able to clearly define the term 'engagement,' which is a critical aspect of understanding the effectiveness of VR in educational settings. Thus, four components we considered with respect to engagement within a VR learning context: -

- Undefined concept of '*engagement*': The respondents' inability to articulate their understanding of engagement suggests a lack of clarity and consensus on what engagement entails. Research should aim to establish a clear definition and measurement of engagement to determine if VR genuinely enhances it within an educational context.
- Flawed assumption of automatic engagement: The quotes point out that the assumption that VR is inherently more engaging than traditional

educational activities may be flawed. This belief needs to be tested, as it is not guaranteed that the mere introduction of VR technology will automatically result in increased engagement.

- Investigate factors contributing to engagement: Further research should explore which aspects of VR experiences contribute to increased engagement. Identifying these elements will help in designing more effective educational VR experiences and in understanding the conditions under which VR can enhance engagement.
- Compare VR with traditional methods: Additional studies should compare VR-based educational experiences with traditional teaching methods to assess their relative effectiveness. This will help educators and policymakers make informed decisions about the potential benefits and limitations of VR in education.

In summary, while VR may hold promise for enhancing education, further research is needed to validate the assumption that it automatically increases engagement. This chapter looks to provide clearer definition of engagement, comparison of VR with traditional teaching methods and an exploration of the factors contributing to engagement.

Additionally, educators were receptive of VR in the classroom and had some interesting use cases they would like to apply VR to. One of these use cases was thought exercises. This aligned well with the existing literature suggesting that teaching programming is a challenging task. Therefore, it was decided to combine this issue with educator's desire to use VR for thought exercises by creating an artifact that explored this through developing students logical thinking skills. In concert, this chapter also takes the opportunity to assess the level of engagement displayed by students within a VR educational system in comparison to traditional desktop implementations.

Therefore, in this section, engagement is explored through VR-based learning tools by contributing LogiBot, a VR artefact that aims to teach programming concepts through gamification. A comparison study was conducted comparing LogiBot against another block-based programming learning environment, LightBot. This study aims to validate the widely held assumption that VR inherently increases educational engagement by comparing engagement levels in VR (using LogiBot) and a traditional programming environment (using LightBot). The study addresses the lack of a clear definition and measurement of 'engagement' in the context of VR in education, employing the User Engagement Scale (UES) [175] for a more precise analysis. Additionally, it seeks to identify specific elements within VR experiences that contribute to engagement, thereby informing the design of more effective VR educational tools. Lastly, the focus on programming and logical thinking aligns with educators' interests and existing literature, exploring VR's potential in enhancing logical skills compared to conventional methods, thus offering an understanding of VR's role in educational settings.

5.2 Background

5.2.1 Engagement

A key parameter in learning is engagement. While e-learning tries to trigger psychological engagement through behavioural activities, such as selecting an answer from a list, this is not always successful [46]. On their own, traditional e-learning methods based purely on the dissemination of information are not enough to enable knowledge acquisition for learners. Instead, e-learning needs to provide an experience that participants can learn from.

Virtual Reality (VR) technologies offer a potential solution to this problem. This idea is supported by early research showing that VR provides students with successful experiences in a compelling environment [35], and that the experience of immersion offered by VR makes it an ideal solution for use in education [198]. There is evidence showing that users (particularly children) are more likely to engage with materials that offer a tangible object that they can interact with [104].

One peculiarity in the existing research however is that it is difficult to find single, well-respected definition of the term 'engagement'. This is further compounded by the fact that there appears to be different interpretations of the term depending on the context, i.e., within education or within VR. This chapter therefore attempts to synthesise a definition here from the existing literature [59, 82, 162, 163] in terms of both education and VR and provide the following:

- Engagement, within an educational context, refers to the level of involvement, interest, and commitment that students exhibit towards their learning process. It encompasses various dimensions, including emotional, cognitive, and behavioural engagement. Emotional engagement pertains to students' feelings and attitudes towards learning, cognitive engagement involves their mental effort and investment in understanding the material, and behavioural engagement relates to their active participation in learning activities.
- In the context of VR, engagement refers to the degree to which users are immersed, attentive, and emotionally and cognitively involved in the VR experience. The difference between educational engagement and VR engagement lies in the nature of the learning environment and the specific technologies involved. VR engagement focuses on the user's interaction with the virtual environment and the extent to which it captures their attention and stimulates their senses, while educational engagement is broader and encompasses multiple aspects of students' relationship with their learning process.

Having defined the above separate definitions (educational engagement vs VR engagement), a broader definition of educational VR engagement can postulated as follows:

- Educational VR engagement is the level of involvement, interest, and commitment students exhibit towards their learning process within a virtual environment. It combines emotional, cognitive, and behavioural dimensions, encompassing students' feelings and attitudes towards learning, their mental effort and investment in understanding the material, and their active participation in VR activities. This engagement focuses on users' immersion, attentiveness, and emotional and cognitive involvement with the virtual environment, capturing their attention and stimulating their senses while maintaining a strong connection to the broader learning process.

5.3 Methodology

This chapter compares an existing block-based programming learning game, LightBot, and another, LogiBot, developed in a similar style to be broadly comparable. It was decided to teach programming concepts using the gamification approach championed by LightBot that combines a simplified version of the visual block-based interaction style presented by applications such as Scratch.

The hypotheses formulated for this study are directly connected to the initial research findings highlighted in previous chapters. This research emphasised the need for a clearer understanding of the potential of VR in enhancing educational engagement and developing computational thinking skills. Based on these findings, the study proposes two hypotheses: H1, which posits that VR will be more engaging compared to desktop learning applications, and H2, suggesting that this higher level of engagement will be attributed to the high interactivity with tangible objects within the VR game environment. These hypotheses are grounded in the initial research insights, particularly the assumptions around VR's inherent capacity to increase engagement and interactivity in educational settings.

The hypotheses H1 and H2, are pivotal in investigating the potential of VR to enhance educational engagement and develop computational thinking skills. H1's focus on VR's engagement potential compared to traditional desktop applications, and H2's exploration of the role of tangible interactions in VR environments, directly contribute to understanding how VR can foster engaging educational activities. The shift from using the term ‘hypotheses’ to ‘assumptions’, particularly in reference to H2, reflects the study's methodological approach. The qualitative data from interviews, although not suitable for formal hypothesis testing due to its nature, is instrumental in exploring the underlying assumptions about VR's educational impact. This approach is consistent with the mixed-methods framework of the study, which employs quantitative data for hypothesis testing while leveraging qualitative insights for a deeper understanding of VR's role in education. Thus, this chapter's analysis of LightBot and LogiBot, and the subsequent hypotheses, are crucial for answering how VR can be utilized to create engaging and interactive educational experiences, addressing both RQ1 and RQ1.1.

5.3.1 Task

Participants in the study were required to solve a series of computational thinking tasks using the LogiBot VR programme. On the basis of their performance in completing the puzzles and their self-reported levels of involvement and satisfaction, the levels of engagement by the participants were also assessed.

5.3.2 Data Collection

The study employed a mixed-methods approach, collecting and analysing both quantitative and qualitative data. The quantitative data includes indicators of effectiveness, such as task completion time and accuracy, while the qualitative data was gathered through questionnaires and interviews to determine the thoughts and experiences of the participants using the LogiBot application. This approach to data collection and analysis, including both quantitative and qualitative measures, was used to provide a more holistic understanding of the effectiveness of the LogiBot VR application for promoting engagement and developing computational thinking skills.

5.3.3 Development of Survey and Interview Instruments

The survey and interview instruments used in this study were carefully developed to align with the research objectives of evaluating the effectiveness of VR in education, specifically in enhancing student engagement and logical thinking skills. The survey instrument was an off-the-shelf tool - the User Engagement Scale (UES), which was chosen due to its comprehensive approach in measuring various dimensions of user engagement. This scale has been validated in numerous studies and is widely recognised for its reliability in assessing engagement in digital environments, making it an appropriate choice for our study focusing on VR applications.

The development of the interview questions was informed by the preliminary findings from the survey responses and aimed to delve deeper into the qualitative aspects of user experience with VR in education. These questions were designed to explore participants' subjective experiences, perceptions, and suggestions regarding the use of VR in educational settings. The inspiration for these questions came from a thorough review of existing literature in the field of VR in education and the feedback from educators as highlighted in earlier chapters of this study.

The survey questions are designed to capture a comprehensive view of user engagement, encompassing aspects such as focused attention, perceived usability, aesthetic appeal, and reward factor. These dimensions are relevant to understanding the user experience in a VR learning environment. The interview questions, on the other hand, were more open-ended, allowing participants to express their thoughts and experiences more freely. These questions focused on aspects such as the perceived effectiveness of VR in enhancing learning, the challenges faced while using VR tools, and suggestions for improvement.

The use of the survey and interview instruments was guided by both theoretical frameworks and practical insights from previous studies. This approach ensured that the instruments were well-suited to capture the nuances of user engagement and experience with VR in an educational setting.

5.3.4 Observations

A structured observational approach was employed to gather insights into the participants' interactions with the VR educational tool, LogiBot, and the traditional desktop-based programming environment, LightBot. The observations focused on behavioural aspects, such as the participants' physical interactions with the VR headset and controllers, their body language, and facial expressions during the tasks. These observations provided an understanding the nuances of user engagement and interaction within the VR environment. The researchers were trained to observe specific behaviours that could indicate levels of engagement, ease of use, and potential usability issues with the VR system. This included noting how participants navigated the VR space, their reactions to VR stimuli, and any verbal or non-verbal indications of frustration or enjoyment. Observational data was recorded in real-time, ensuring that subtle yet significant participant behaviours were captured accurately. This approach allowed for a an assessment of the VR experience, complementing the quantitative and qualitative data collected through other methods. By integrating these observations, the study aimed to provide a holistic understanding of the impact of VR in educational settings, particularly in relation to engagement and user experience.

5.4 System design

5.4.1 Platform

The chosen platform to develop LogiBot on was Unity, a cross-platform 3D game engine that supports scripting in the C# language as well as various virtual reality headset SDKs. Within Unity the development also used a framework called Virtual Reality Toolkit (VRTK) [264]. VRTK is a general-purpose framework for developing virtual reality games, providing a number of 'out of the box' interactions for motion-tracked virtual reality controllers. Unity was used to develop the game whilst targeting the Oculus Go headset, which builds on top of Android as a development and delivery platform. For the purposes of development, a Samsung Gear VR headset paired with a Samsung Galaxy S7 smartphone was used, which has the same hardware capabilities and SDK as the Oculus Go.

5.4.2 Implementation

A key design decision was where possible to implement interactions via interactable objects and so minimise the use of GUI based elements (floating menus, start/stop buttons et cetera). As an initial prototype, a simplified graphical elements was used and thus the objects within game were not textured and did not have complex lighting applied. Robot instruction types were defined

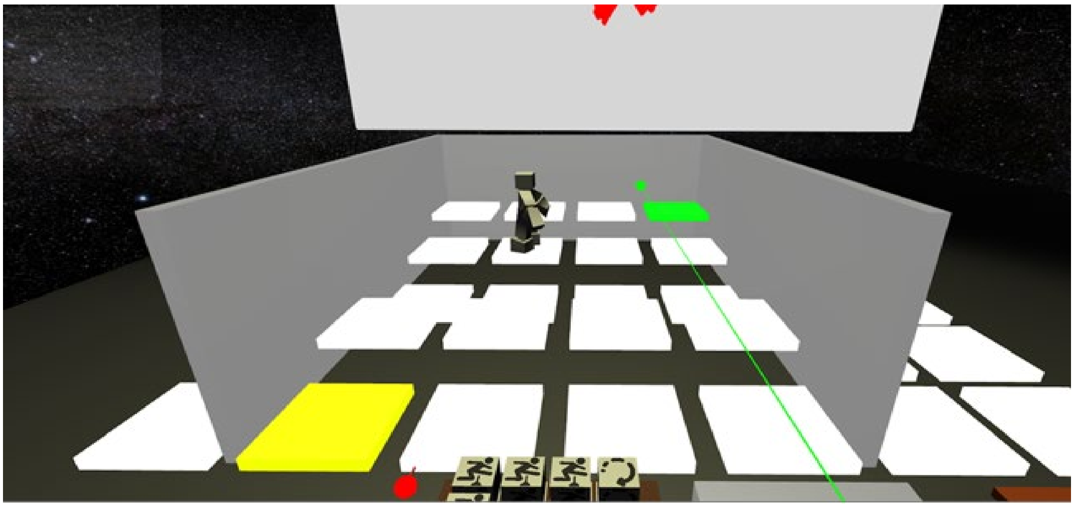


Figure 5.1 Example level in LogiBot

Level requires a combination of command blocks used procedurally to complete the level

as "Forward", "Rotate Clockwise", "Rotate Anti-clockwise", "Jump", and "None". Instructions include a 1-second wait between each executed instruction. An example is the forward function, which when executed will simply make the robot move one space forward in the maze. For this initial study, five hand-programmed levels (figure 5.1) were implemented in the game, declaring the positions of the tiles, walls, and objectives. Creating a more dynamic system that could read in level files (in JSON/CSV format) was considered, but for the purposes of the prototype, it was decided to manually implement each one as it would be more time-efficient for only five levels.

5.4.3 Interaction Design

The 3DoF controls of the Oculus Go necessitated certain choices being made for interaction techniques, e.g., for pointing and selection. Laser pointers (ray-casting) have been demonstrated as an efficient way of interacting with onscreen keyboards [243] so a similar approach was applied to selecting and grabbing interactable objects within LogiBot. A mechanism to move objects towards and away from the controller was implemented using the trackpad on the Oculus Go. A user alters the object distance by swiping up or down on the touchpad, although the

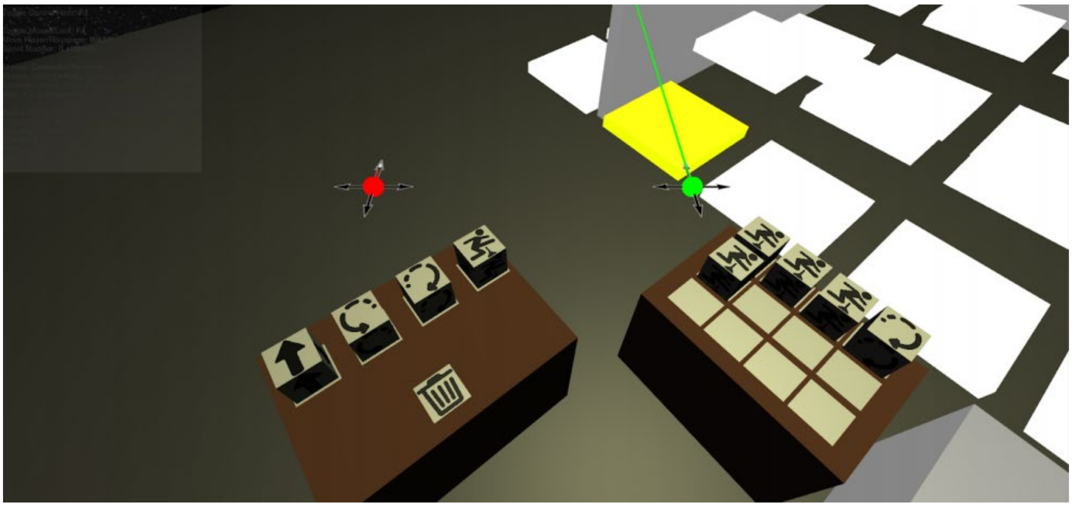


Figure 5.2 Screenshot of instruction blocks table.

requirement to adjust object distances was somewhat minimised by effective level design and careful consideration of object placement in the scene at run time.

Object manipulation was implemented in the form of pointing the controller at object (ray-cast), pressing the trigger to pick up the object, or clicking the touchpad down to "use" the object, which is a context-sensitive action (e.g., using the "trash" button next to the instruction block grid empties it of all blocks currently placed in it). Objects that have been picked up are suspended in the air and move relative to the controller when the player moves it.

Instruction grids are 4 by 3 grids of slots (figure 5.2) that users can place instruction blocks on to build their solutions to the robot maze. The main grid (that appears in every level) is used to create the program that the robot will execute, but another appears on the last level of the game - the procedure grid. Blocks that are dragged close to a grid will automatically snap to the first free slot on that board when the player releases their grip on the block. The grids build a list of instructions from the blocks by reading the blocks from the top-left to the bottom-right, which is then passed to either the robot directly, or the procedure block. Instruction blocks can be added to the main grid by either attempting to grab one of the "template" blocks, of which there is one for each instruction type. This creates a copy of that block type which the players grab instead, or by "using" the template block, which automatically inserts a copy of

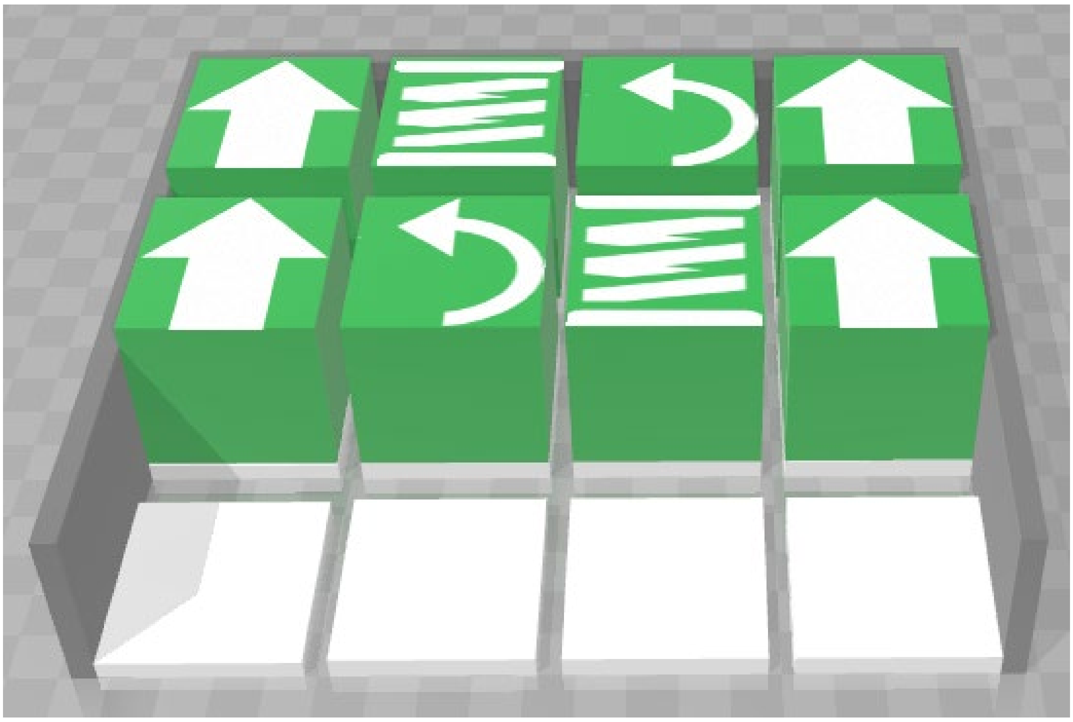


Figure 5.3 An example solution to level 3 in LogiBot.

the block type in the first free slot on the board. Blocks can be removed from the grid they sit in by grabbing them and moving them. Blocks can be placed anywhere in the play area. An example solution to a level can be seen in figure 5.3.

5.4.4 Comparison Between LightBot and LogiBot

Table 2 Comparison between LightBot and LogiBot

Feature	LightBot	LogiBot
Platform	Desktop (Web-based)	Virtual Reality (Oculus Go)
Learning Approach	Simplified block-based programming	VR-enhanced block-based programming
User Interface	Traditional desktop interface	Immersive 3D VR environment
Interaction Style	Point-and-click navigation	3D interaction with VR controllers (e.g., grabbing, placing)
Programming Concepts	Basic programming logic (e.g., sequences, loops)	Basic programming logic (e.g., procedures, nested loops)
Usability	High (familiar interface)	Medium (requires adaptation to VR controls)
Engagement Features	Structured puzzles, clear instructions	Immersive gameplay, tangible interaction

This table highlights the key differences between the two applications in terms of platform, learning approach, user interface, interaction style, programming concepts, usability, and engagement features. It provides a clear comparative overview that can be useful to understand the distinct characteristics and functionalities of each tool.

5.5 Experiment

5.5.1 Apparatus

The control group were provided with a laptop with the required software installed and LightBot loaded, while the experimental group were provided with a VR headset (Oculus Go) to complete the tasks, and a laptop to complete the UES [175]. The entire experimental task was designed to take 20-30 minutes, while the post-task questionnaire and interview took 30 minutes to complete.

5.5.2 Participants

The study was run with 10 participants. Participants were recruited from current students and alumni of Lancaster University. The sample was split into two groups for a between-subjects study, one group using LogiBot and the other using LightBot. Six participants completed the LogiBot tasks and four completed the LightBot tasks. The demographics of participants completing the study were 3F, 7M, age 18-55.

5.5.3 Task

Before commencing the tasks, participants were provided with clear and concise instructions to ensure they understood the objectives of the study and how to interact with both the LogiBot and LightBot tools. For the LogiBot VR program, participants were guided on how to use the VR headset and controllers, including navigating the virtual environment and manipulating the programming blocks. For the LightBot desktop application, instructions were given on how to navigate the interface using standard desktop controls. Participants were informed that the purpose of the study was to compare engagement and learning effectiveness between the VR and desktop-based programming environments. They were encouraged to interact with the tools as they would in a typical learning scenario and were assured that their performance in the tasks was not being evaluated, but rather their experience and engagement with the tools.

Participants in the LightBot condition were instructed to complete section 1 - basics and section 2 - procedures. The LogiBot participants were instructed to complete the five levels. 20 - 30 minutes was allowed for this section of the study. Observation notes were collected by the researchers for behaviours that were deemed interesting. On completing the task, both groups of participants were asked to complete the UES. Finally, short semi-structured interviews were conducted with participants to probe them on their motivations and insights when carrying out the tasks. Common questions revolve around the perceived learnability of the system, as well as comfort of the VR headset.

5.5.4 Metrics

Engagement was measured using O'Brien et al.'s long form UES [175], which consists of thirty 5-point Likert style questions measuring four latent variables – focused attention, perceived usability, aesthetic appeal and reward factor (see appendix B.2) and has been used previously to measure engagement in VR games [136]. Each of these sub scores are averaged for each category and the totals summed together to derive an overall score.

The UES is a validated tool [23, 64, 79] for assessing the user experience of digital products, such as websites, mobile apps, and other interactive systems. In the context of HCI, the UES can be instrumental in designing effective applications by providing valuable insights into users' perceptions, needs, and preferences throughout various stages of the design process, including planning, development, and evaluation.

During the development phase, the UES can be employed to assess prototype versions of an application. By gathering feedback from users at this stage, designers can identify any issues or areas for improvement before the application's final release. This allows designers to make necessary changes and refinements to the application, ensuring it meets users' expectations and provides an optimal user experience. By identifying user needs and preferences, informing the design process, and facilitating ongoing evaluation and improvements, the UES enables designers to create applications that provide a positive and engaging user experience.

Further measurements were in the form of event sampled observations based on user behaviour during the experiment, accompanied by a semi-structured interviews to explore thoughts and motivations of the users during the study. The justification for choosing semi-structured interview for this study are the same as those detailed in chapter three, part 3.2.3.

5.6 Results

5.6.1 UES

In this study, a p-value threshold of less than 0.05 is employed to determine the statistical significance of results, thus guiding the rejection or acceptance of hypotheses.

The survey results were analysed through independent sample t-tests. In comparing the LightBot and LogiBot survey responses, statistically significant difference was found in focused attention for the applications, LightBot ($M = 4.4$, $SD = .38$) was significantly higher than LogiBot ($M = 3.9$, $SD = .45$), $t(8) = 1.91$; $p < .05$. A statistically significant difference was found in perceived usability for the applications, LightBot ($M = 4.1$, $SD = .28$) was significantly higher than LogiBot ($M = 3.1$, $SD = .68$), $t(8) = 2.28$; $p < .05$. There was no significant difference in the aesthetic appeal for LightBot ($M = 4.2$, $SD = .63$) as compared to LogiBot ($M = 3.7$, $SD = .90$), $t(8) = 1.01$, $p = 0.34$. There was no significant difference in the reward factor for LightBot ($M = 4.45$, SD = .39) as compared to LogiBot (M=3.7, $SD = .85$), $t(8) = 1.8$, $p = 0.11$. These results are reported in table 3 and visualised in figure 5.4.

Table 3 UES scores and paired-samples t-test reults.

	Focused Attention	Perceived Usability	Aesthetic Appeal	Reward Factor
LogiBot	3.9 (±.45)	3.1 (±.68)	3.7 (±.90)	3.7 (±.85)
LightBot	4.4 (±.38)	4.1 (±.28)	4.2 (±.63)	4.45 (±.39)

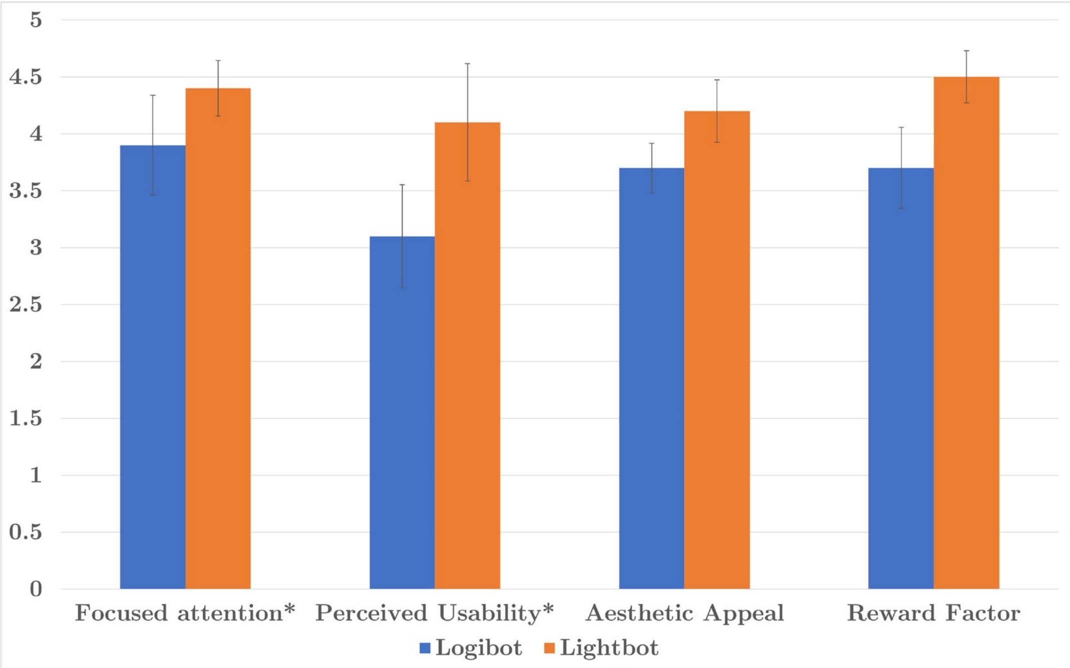


Figure 5.4 Comparison between LightBot and LogiBot

Mean responses grouped as latent variables. Reverse scale correction applied. *indicates significant difference.

t-test	$t(8) = 1.91; p < .05$	$t(8) = 2.28; p < .05$	$t(8) = 1.01, p = 0.34$	$t(8) = 1.8, p = 0.11$

5.6.2 Interviews

Interview responses indicated that participants for both LightBot and LogiBot were more likely to explore the interface independently as opposed to following on screen instructions. Both sets of participants recognised the value of such learning games in respect to learning programming and commented "*bit like one of the programmable robot toys*". LightBot participants said it was good for practicing "*solving structural problems*". For LogiBot a lot of the responses centred around the interaction methods and the clarity of the instructions provided, for example "*vague instructions*" and "*instructions lacked context*". The VR headband impacted upon the comfort level of participants. They commented on how it can be loose at times during gameplay, which draws attention away from the game. The headband had a tendency to get hot over time, which participants noted may make them less likely to play the game for a long period of time.

For LogiBot, a common issue for participants was the way instructions were presented at the beginning of the game using text. They found this to be vague and confusing and would rather have seen a visual example of how to solve a level before starting. For instance, one participant pointed out that they initially tried to place instruction blocks on the robots table and tried to place the robot on the instruction table rather than the yellow block. They enjoyed the dragging interaction as it was easier to drag, since they could not see the controller while playing the game. Some participants commented on the scaling of the levels, saying that the difficulty scales too quickly. One participant did not find LogiBot useful in teaching programming concepts. They argued that people will already have these skills before playing the game (structural problem solving). They also did not think that VR was a necessary tool for these kinds of problem-solving exercises. Many participants noted frustration with trying to grab items such as blocks and the robot, sometimes picking up the wrong block, and placing the robot on the platform.

5.6.3 Observations

Observations indicated that while the experience was a seated experience, participants still displayed significant ranges of movement. Correlation to interview responses indicate one of the reasons for this was that the table with the instruction blocks on it was too far to the left participants field of view, necessitating them to have to twist uncomfortably to see the instruction block table. In a couple of observations, participants did not locate the instructions block table for a considerable amount of time, leading to frustrations being evident.

5.7 Discussion

The results show that the Perceived Usability and Focused Attention for LightBot scored significantly higher than LogiBot, indicating that the VR interface of LogiBot does not significantly contribute to user engagement. LightBot scoring higher could be attributed to interface familiarity for desktop applications. This adds interesting design questions for the VR interface and what implementations will allow the users to have a better engagement with the task and therefore the learning process. The neutral results for Aesthetic Appeal for LogiBot indicate that there is less evidence of the 'wow-factor' from using VR applications than is generally assumed. Perhaps with the proliferation of low-cost VR devices such as the Oculus Go or Quest, VR is treated as more common-place or expected. The users thus possibly expect better functionality and interaction mechanisms beyond typical 'roller-coaster demos' bundled with past VR headsets.

LogiBot implemented basic reward factors, limited to congratulation messages and sounds on level completion. Neutral results indicate reward mechanics did not dominate user experience over learning for both applications. There are opportunities to enhance engagement through gamification mechanics as a part of the learning process.

The results indicate that in its current form LogiBot is not more engaging than LightBot and by extension VR is not automatically more engaging than desktop applications, thus H1 is rejected while also making H2 invalid. In analysing the interview responses, ease of use and interaction methods were identified as the main barriers in preventing the LogiBot application from being more engaging. If these issues are addressed, it could be inferred that VR has the potential to be a key element of learning applications by increasing engagement.

Overall, the observations show that it may be necessary to think more deeply about interactions for VR applications versus traditional desktop applications, including identifying an acceptable range of motion for different experiences, i.e., seated or standing. The difficulty in implementing effective interactions can somewhat be ascribed to the limitations of the Oculus Go and its 3DoF tracking. This seems to support the notion that low-cost VR devices are more suited to content consumption rather than reflective interaction with the content.

5.8 Limitations and Future Work

As a preliminary exploratory study, the number of study participants was low. A future iteration would aim to conduct a thorough play test of LogiBot with additional participants to identify further interaction issues to be solved. With the launch of the Oculus Quest (and Quest 2), porting LogiBot to this device would be a logical step, which will increase the options for interactions, and it would be interesting to see if this has any impact on the level of engagement experienced by users.

For a further exploration of engagement within VR, individual differences should be considered: Students have different learning styles, preferences, and levels of experience with technology. Future research should investigate how these factors might influence engagement with VR-based educational activities and explore ways to personalise VR experiences to cater to diverse learners.

Additionally, while the LogiBot artifact proved to be usable and enjoyable by students to learn computational thinking, the effectiveness of this learning was not assessed within this study.

Finally, this study failed to conduct a Simulator Sickness Questionnaire (SSQ). If it had, there is a possibility that their might have been some correlation between the SSQ answers and the responses to the UES, although there was no observation of any obvious discomfort among participants.

5.9 Conclusion

This chapter presents the findings of a study examining the implementation and effectiveness of computational thinking and engagement in VR-based block-programming games, specifically addressing RQ1 and RQ1.1. The study's comparison of the VR-based LogiBot and the desktop-based LightBot provides insights into the current state of VR in educational settings, particularly in the context of low-cost VR devices and their capacity to support engaging, interactive educational experiences. The results show that, contrary to the initial hypothesis (H1), VR, as represented by LogiBot, does not automatically guarantee higher engagement compared to desktop applications like LightBot. This finding is crucial for addressing RQ1, suggesting that the mere presence of VR technology does not inherently enhance educational engagement.

Furthermore, the study's exploration of interaction paradigms and methods in VR (RQ1.1) reveals significant insights. The higher usability and focused attention scores for LightBot imply that familiarity with desktop interfaces currently trumps the novel experience of VR in LogiBot. This challenges the assumption that VR's 'wow-factor' alone can boost engagement and underscores the need for well-designed interaction mechanisms in VR educational tools. The neutral results for aesthetic appeal in LogiBot also question the common assumption of VR's inherent attractiveness, further highlighting the importance of effective interaction design in VR for educational purposes.

The study also sheds light on the potential of VR in enhancing educational experiences if interaction and usability barriers are addressed. This finding is particularly relevant for RQ1.1, as it emphasises the need for more research into creating engaging and interactive VR educational experiences, beyond just leveraging the novelty of VR technology.

Chapter 6

VERITAS: Mind mapping in Virtual Reality

6.1 Introduction

In the previous chapter the concept of engagement within VR, utilising an artifact called LogiBot, was investigated. Student engagement and the development of computational thinking skills were both considered. Participants in the study utilised the LogiBot VR artefact to complete computational thinking tasks that needed logical reasoning and problem-solving abilities. It was discovered that LogiBot was not more engaging than a comparable desktop application, postulating that due to familiarity, VR can no longer be considered to be engaging just by way of novelty. This stresses the significance of creating VR applications with interactivity in mind in order to increase user engagement. The results indicate that the usage of VR can create a unique and immersive learning experiences that can increase student engagement and knowledge retention, but it must be implemented with care to be effective.

This chapter therefore conducts an additional study to carefully consider how VR applications can be designed and built with interactions in mind to encourage engagement and subsequently facilitate improved learning outcomes.

6.2 Motivation

VR has the potential to significantly impact education and specifically students' engagement in the learning process [177, 185, 203]. Recent advances in VR technology have made low-cost untethered VR headsets accessible to more users. Low-cost VR devices such as the Oculus Go and Meta Quest are untethered and consequently more manageable in a traditional classroom environment. Due to the untethered nature, these devices also present the intriguing possibility of being included by educational institutions in their flipped learning strategy [1].

Beyond the novelty factor of VR headsets, it is essential to understand the exact use which benefits the learning process. Commercially, low-cost devices are geared toward content consumption rather than content creation. Educational institutions commonly use VR as exploration devices, such as viewing 360-degree videos of interesting places on earth, visualising chemical structures or viewing parts of the galaxy. These activities are typically passive in nature, with limited interactivity and as such address only the lower cognitive processes, such as those illustrated in Blooms Taxonomy [24] of remembering and understanding. Conversely, inquiry based learning [190] incorporates reflective tasks such as categorising, organising, differentiation and interpretation. The aim is to trigger the more advanced cognitive processes of applying and analysis. Examples of reflective tasks currently used within education include white boarding and mind maps [2, 271]. These reflective tasks are known to show benefits over teacher-led learning [231]. However, in the VR domain there are very few applications that support interactive reflection.

6.3 Methodology

This chapter develops a VR artifact, VERITAS, to explore a mind mapping tasks as an opportunity to explore abstractly structured reflection within a 3D spatial environment. The focus is on individual reflection and the role of VR in supporting this process as a starting point for investigating VR supported reflection in paragogy (peer-based learning). Participants in the study were instructed to complete a mind mapping activity using VERITAS. The participants were evaluated based on their task performance and self-reported levels of involvement and satisfaction. The study employed a mixed-methods approach, integrating the gathering and analysis of quantitative and qualitative data. The quantitative data includes indicators of ease of use, such as task completion time and accuracy, while the qualitative data was gathered through questionnaires and interviews to determine the thoughts and experiences of the participants with the VERITAS application from a usability perspective. This strategy to data collecting and analysis, including both quantitative and qualitative measurements, was utilised in this study to provide a more holistic picture of the effectiveness of VERITAS VR for mind mapping.

The main contributions of this section are:

- The concept and analysis of a VR mind mapping application to be used as a scaffolding tool for inquiry-based learning.

- The implementation and analysis of specific complex interactions required for the VR mind mapping application.

- The results of a user experience study and discussion on the learnability of the application.

6.3.1 Surveys and Interviews

The survey and interview instruments were crafted to align with the study's objectives. The User Experience Questionnaire (UEQ), a standard tool in usability studies, was adopted for the survey due to its comprehensive range of parameters covering attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. This approach enabled the capture of a holistic view of the participants' experience with the VR application, VERITAS. The interviews were conducted as unstructured and questions were based on the results and insights gathered from the survey, aiming to delve deeper into specific aspects that were highlighted as significant. These included questions on the ease of use, engagement levels, and any challenges faced while using VERITAS. Statistical Analysis

The analysis of the survey data employed a multifaceted statistical approach. Descriptive statistics were used to provide an overview of the participants' responses, capturing the central tendencies and dispersion within the data. The primary method used was the Analysis of Variance (ANOVA), which allowed for the comparison of the mean scores of different groups. This was particularly useful in evaluating whether the use of VERITAS significantly impacted factors such as engagement and usability. Additionally, correlation analysis was conducted to explore the relationships between different user experience dimensions measured by the UEQ. This statistical approach ensured a rigorous analysis of the survey data, providing robust insights into the effectiveness and user experience of the VERITAS application.

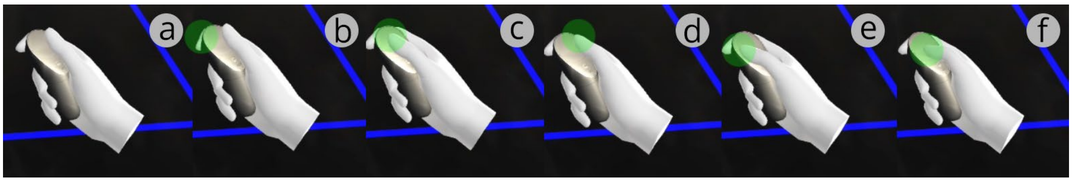


Figure 6.1 Inputs and gestures available on the Oculus Go controller.

The following inputs are available as standard as part of the Oculus SDK in Unity. (a) Controller motion/orientation (3DoF), (b) Trigger press, (c) Touchpad click, (d) Touchpad swipe left/right, (e) Touchpad swipe up/down and (f) touchpad position.

6.4 System Design and Implementation

6.4.1 VR Platform

The motivation for VERITAS is a classroom-based setting where reflective tasks like mind mapping are to be carried out. This presents constraints related to choices like tethering, tracking and control in addition to unit cost and supporting infrastructure. A pilot survey of available hardware indicated that the entire spectrum supported 3DoF controller input at minimum with additional features like clickable buttons, swipe surfaces or joystick alternatives. This formed the baseline for selecting the test hardware. While 6DoF controllers with higher fidelity exist, the interactions this chapter explores can only be further improved by 6DoF (when such become a low-cost option), while continuing to work on existing hardware. The Oculus Go controller includes a touch surface which can interpret swipe gestures in the form of thumb swipe up, down, left, and right (figure 6.1) in order to expand the possible interactions available to the application. The controller also includes a gyroscope for 3DoF input and interactions were built around this also. As a low-cost untethered unit, the Oculus Go acts a flexible VR development platform and the Oculus Integration framework (v1.35). To retain full control of interaction development, no other VR toolkits were used. The platform for implementation. VERITAS is implemented

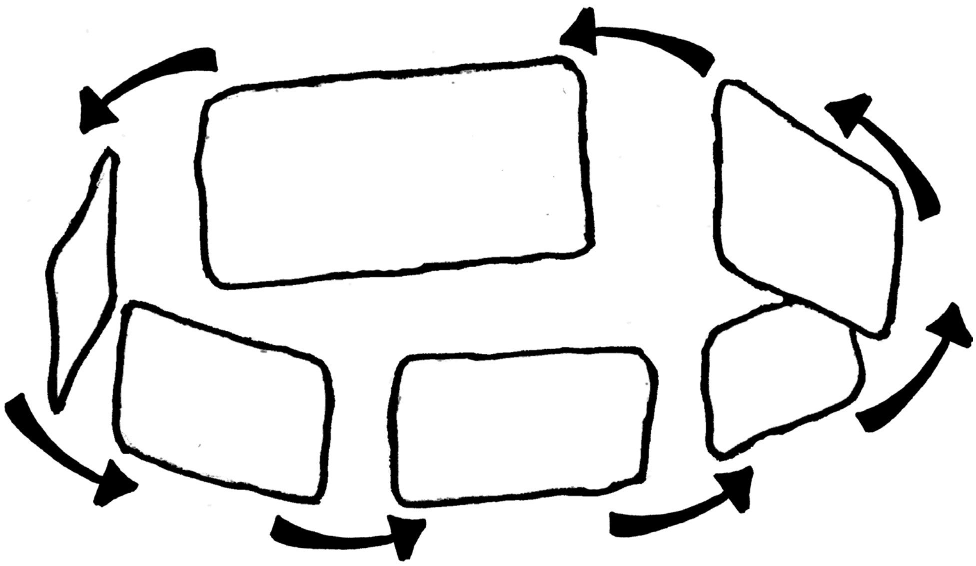


Figure 6.2 Concept of initial tile presentation to the user.

using the Unity game application is forward compatible with Oculus Rift and Quest series of headsets.

6.4.2 System Overview

The primary design goal of VERITAS is to allow participants to build a mind map from pre-defined objects based on information they had previously been exposed to outside of VERITAS. These pieces of unique information could be images or text and needed to be presented as interactive objects. From an interaction perspective, participants can manipulate and arrange these objects and display relationships between these objects. The information objects are represented as double-sided tiles. A tile carries the same content (image or text) on both sides. The tiles are initially presented as a rotating carousel (figure 6.2 and figure 6.3) so users can see all available tiles before deciding on which tile to interact with.

6.4.3 Interactions

Selection of a tile is the entry point for interaction with the mind map. The initial research explored virtual hand techniques [148], a form of object touching [29], gaze based and hand-based ray-casting for the initial pointing interaction that precedes selection. Virtual hand techniques were discounted due to the complex control scheme required to support this technique on 3DoF controllers. Virtual hands require a user to 'reach' out to touch an object, facilitated by the heave motion only available in 6DoF controllers. Ray-casting is a ubiquitous and simple VR selection technique supported trivially by 3DoF controllers. Combined with visual feedback to indicate target-intersection, ray-casting is a powerful selection technique. Ray-casting can also be in the form of a head-pose pointer, controlled by head movement, with the point of origin being between the user's eyes. It

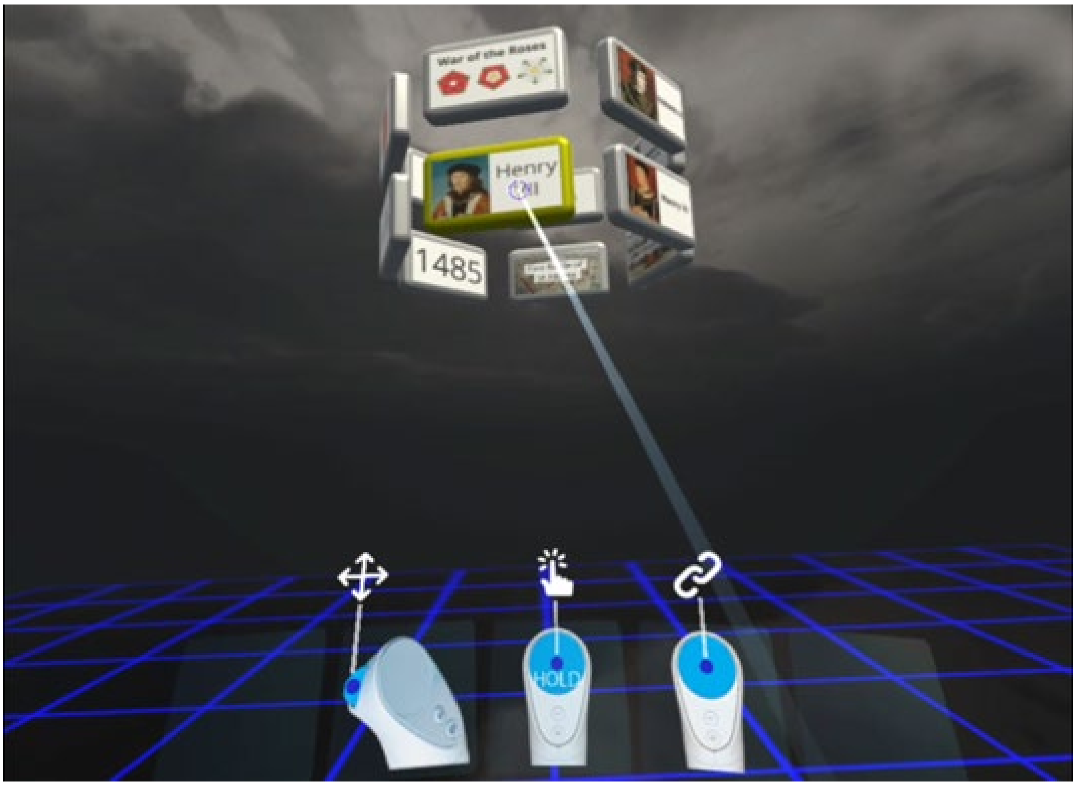


Figure 6.3 Initial 'carousel' of interactive tiles.

requires the user to ‘look’ at the object to be selected. In the implementation, it was decided to decouple the gaze and head-pose from the selection technique so that the user may look around to evaluate the information-rich environment without affecting their ability to select objects. Having considered these approaches, it was decided to implement 3DoF controller-based ray-casting as the selection technique in VERITAS.

Tile selection is via a ray-cast from the controller model. This ray-cast is renders as a faint grey semi-transparent line to aid the user with object selection and emanates from the tip of the controller model. This design decision was informed by Teather and Steurzlingers [255] study that found selection was more accurate when the pointer was rendered from the fingertip rather than the base. When the ray intersects a tile, the tile is highlighted yellow. Further interactions are initiated through controller inputs and the highlight colour changes to green for translation (trigger press), orange for tile manipulation (long-press touchpad button) and blue for link manipulation (touchpad button click). A tile can be ‘dragged’ along an invisible cylindrical plane around the user which ensures that

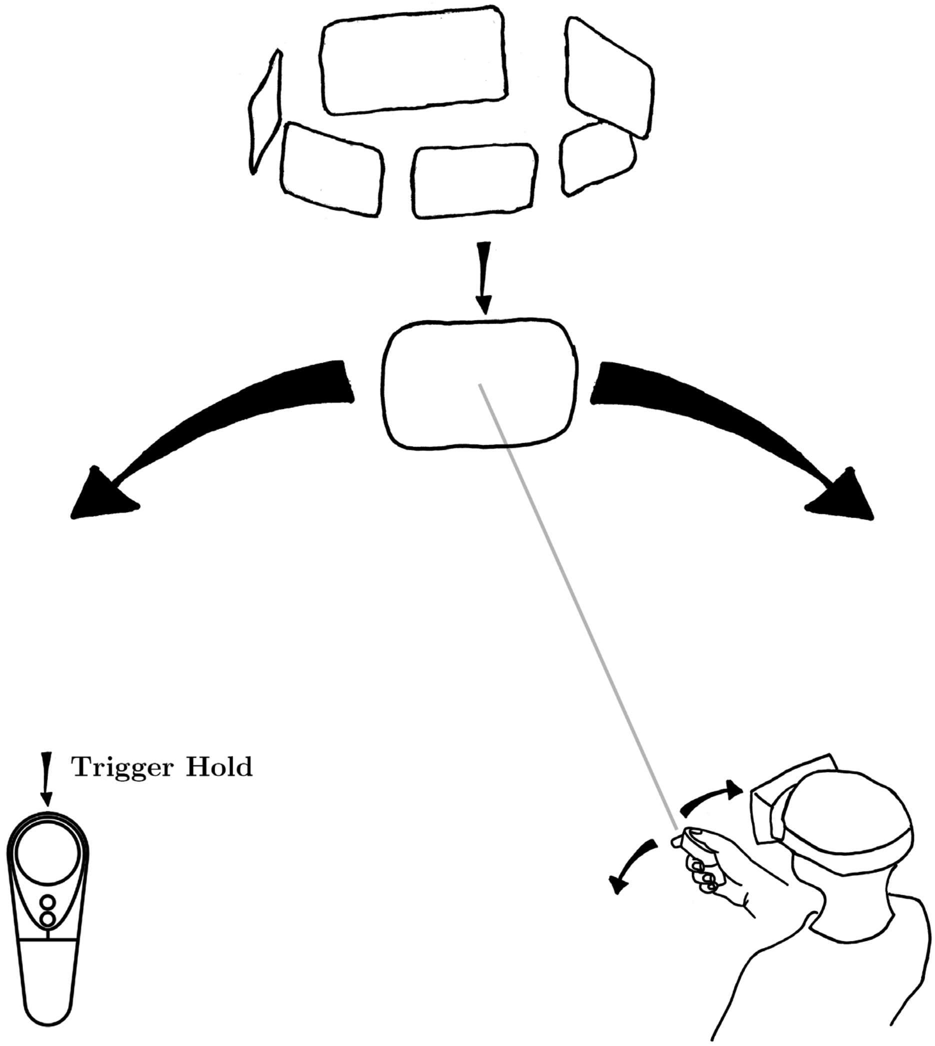


Figure 6.4 Concept for curvilinear translation.

the tile remains at a constant distance from the user's perspective during translation events (figure 6.4 and figure 6.5). This concept of curvilinear

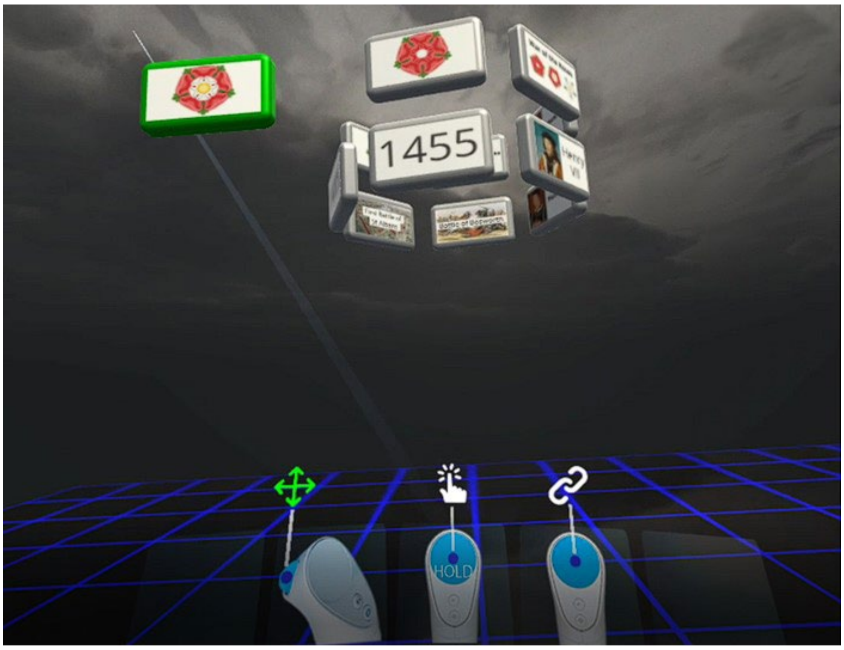


Figure 6.6 Tile translation.

movement can best be illustrated through a log of tile movements (figure 6.6).

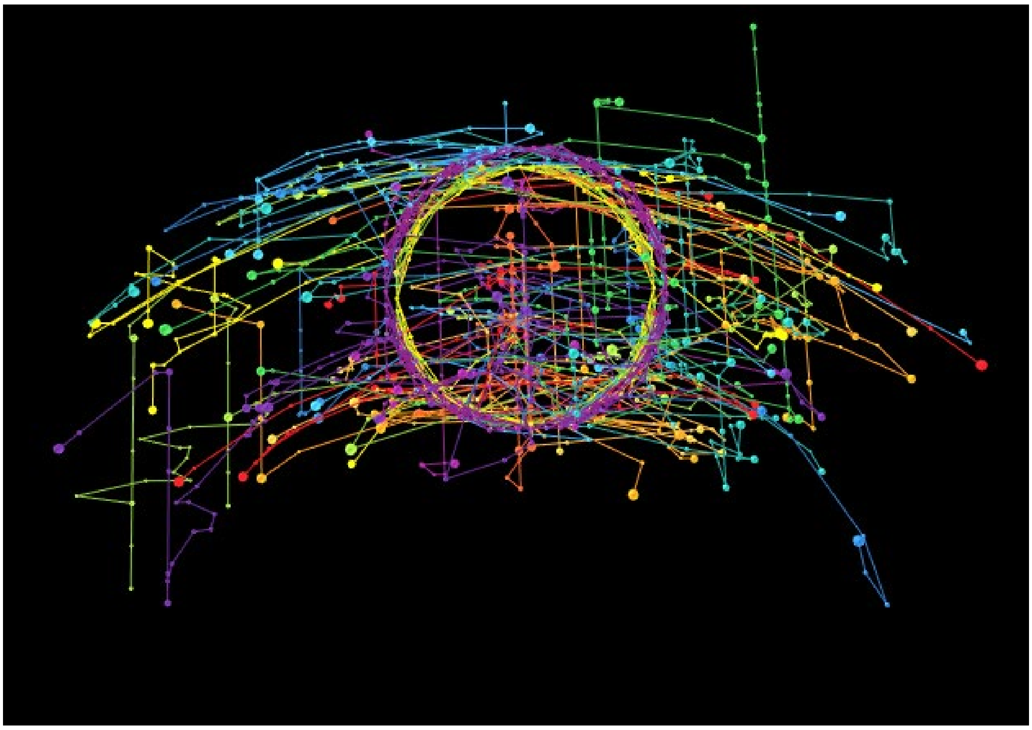


Figure 6.5 Illustration of curvilinear translation.

Perspective is from a top-down view. User location is bottom-middle.

The translation action was separated into planar and depth movement. The planar movement benefits from being a recognisable action in 2D environments as a dragging metaphor. The translation metaphor is thus curvilinear movement at a fixed distance. In VR, this is realised as movement on cylindrical surface to avoid changes in perceived size. The decoupled depth movement is available as an independent interaction using a push-pull metaphor. Scaling an object produces visually similar outcomes to depth movement from the perspective of the user when other depth cues are absent [87]. Thus, the scaling action needs a metaphor that is spatially distinct from push-pull.

Up-down swipe gestures on the touchpad produces movement along the Z-axis (away from or towards the user), resembling push-pull (figure 6.7 and figure 6.8).

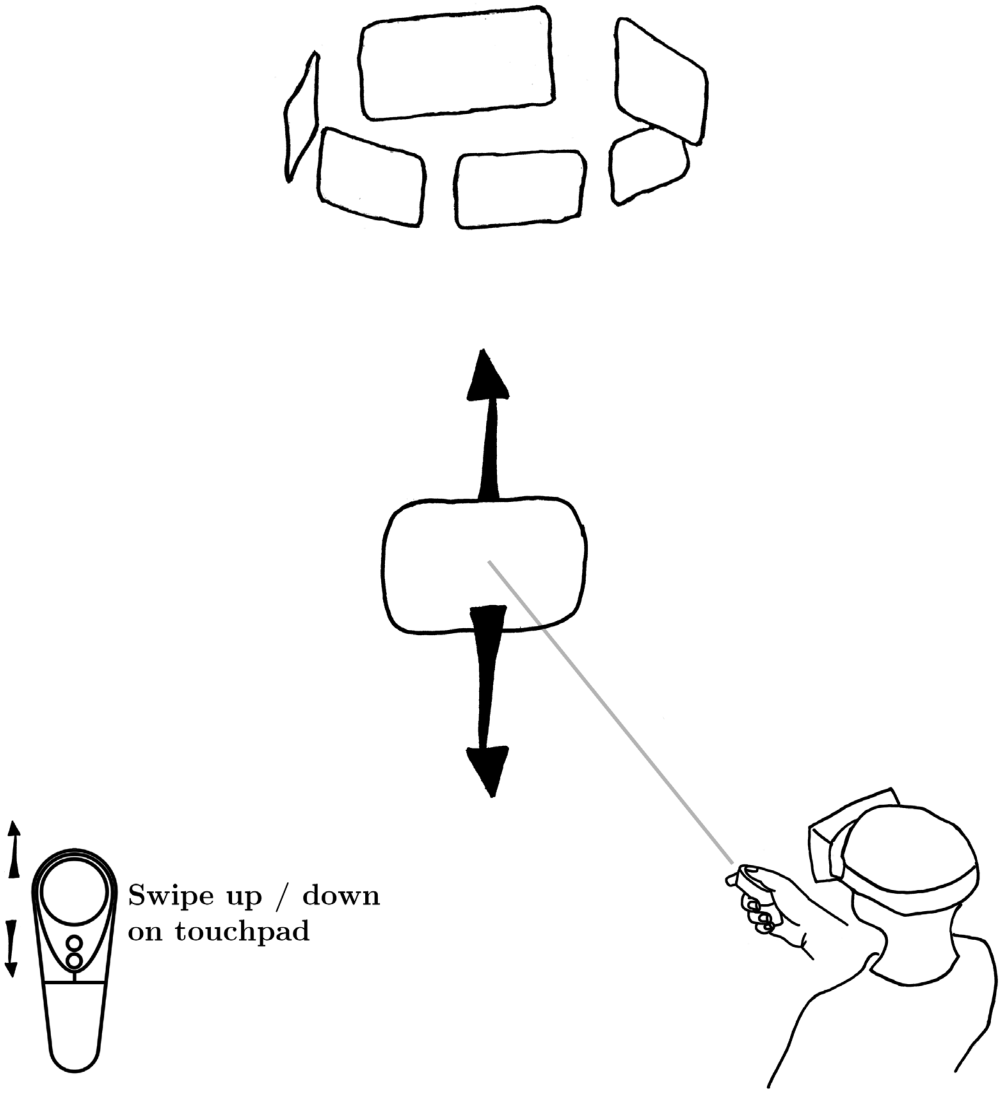


Figure 6.7 Concept for Z-axis translation.

Figure 6.8 Implementation of user induced Z-axis translation.

The interactions to increase or decrease the scale of tile are placed orthogonal (swipe right-left) to Translate-Z interactions. This placement accentuates the difference between the two interactions since they can produce visually similar results.

For rotation, the naïve approach of linking the controller orientation to object orientation as a one-to-one mapping was quickly discarded. This approach can be extremely difficult to control and angles exceeding 30 degrees are hard to achieve without uncomfortable contortion of the wrist. A hysteresis-based approach can be useful here as it can ignore the accidental inputs resulting from manipulating buttons while trying to enter the rotation mode. At the start of the rotation mode, any change in the controller orientation is ignored till it exceeds a threshold angle. This is analogous to a crossing-based interaction metaphor [3] but applied to

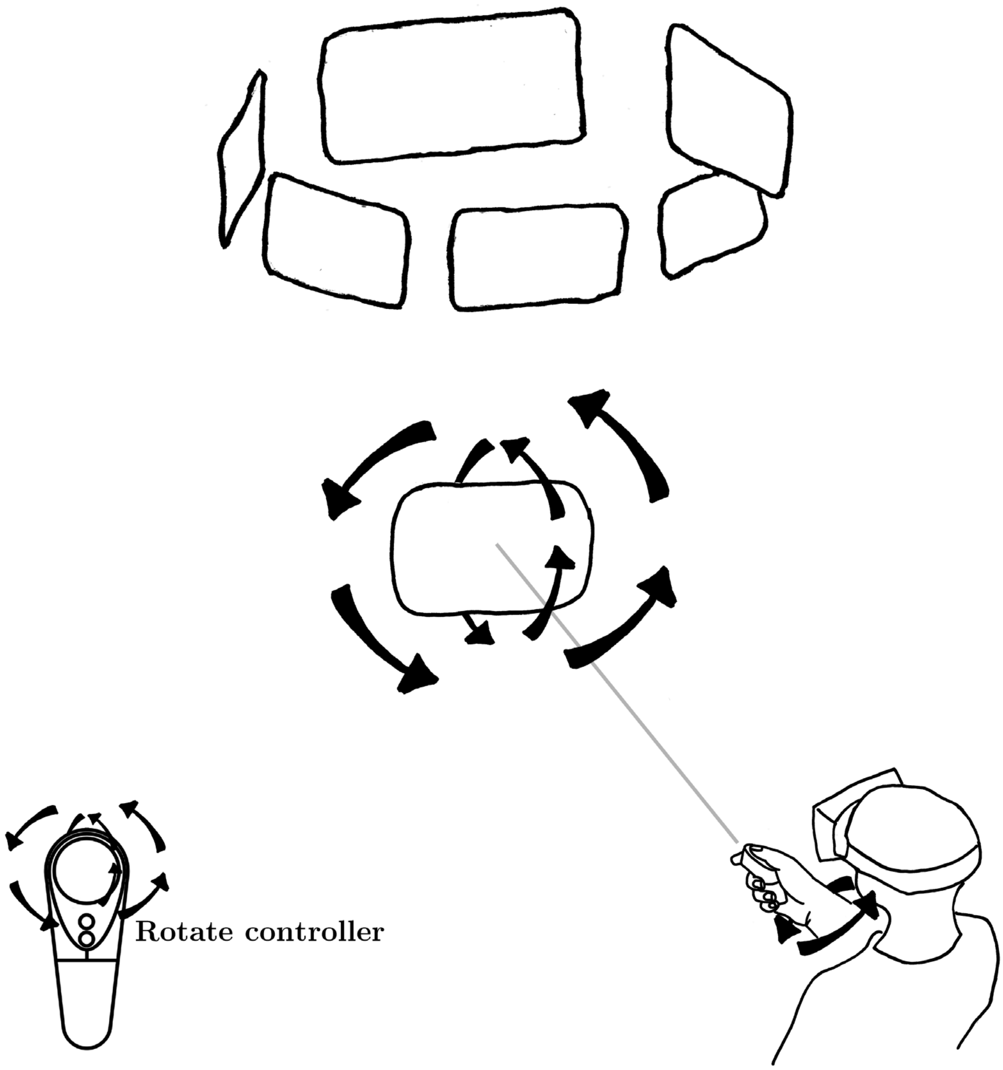


Figure 6.9 Concept for tile orientation.

controller orientation. When the threshold angle is exceeded, object rotation is controlled by coupling the rotation rate to the controller orientation angle along the specific axis. This is analogous to a steering wheel of a car where a specific steering angle produces a fixed turning rate. This was the model thus implemented (figure 6.9). Additionally, for rotating a tile (in all three axis) the system implements visual feedback for rotation as a crossing-interface widget (figure 6.10). The controller rotation beyond the crossing boundary causes the tile to rotate at a specific rate.

Relationships are a crucial element of mind maps, as they help to illustrate the connections between various ideas or concepts. By illustrating how ideas are

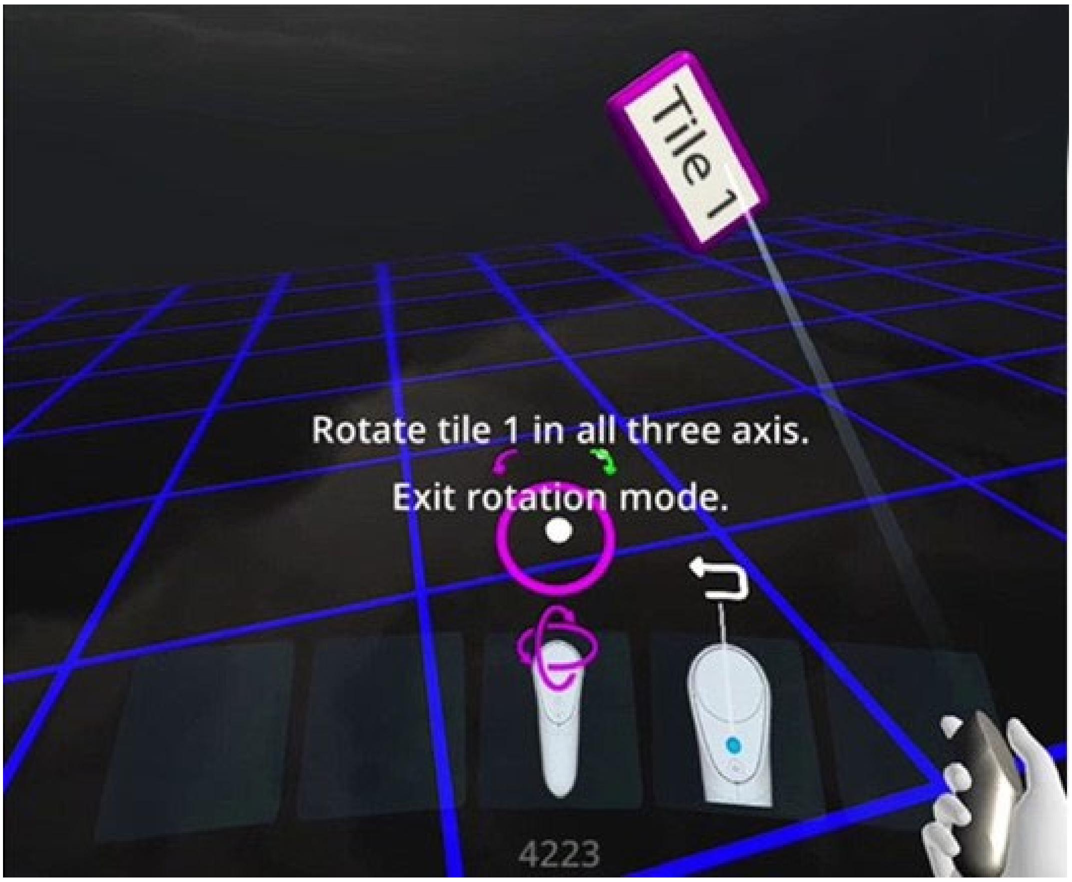


Figure 6.10 Implementation of user induced rotation.

Crossing based interface shown.

interconnected, relationships facilitate a more comprehensive understanding of a topic and can aid in the generation of new concepts. Relationships in mind maps are typically represented by connecting ideas with lines or arrows. These connections can be used to demonstrate cause-and-effect relationships, similarities and differences, hierarchies, and any other relevant type of relationship. Mind maps can also make use of colours and images to illustrate relationships. Related concepts may be grouped together and given the same colour, or they may be represented by images. In VERITAS, relationships between objects are represented by a curvilinear link object (figure 6.11 and figure 6.12). The link connects a parent and child tile on a one-to-many basis and a pulsing animation is applied to the link to show this ‘from-to’ relationship. The links are designed to redraw themselves as the connected tiles are moved.

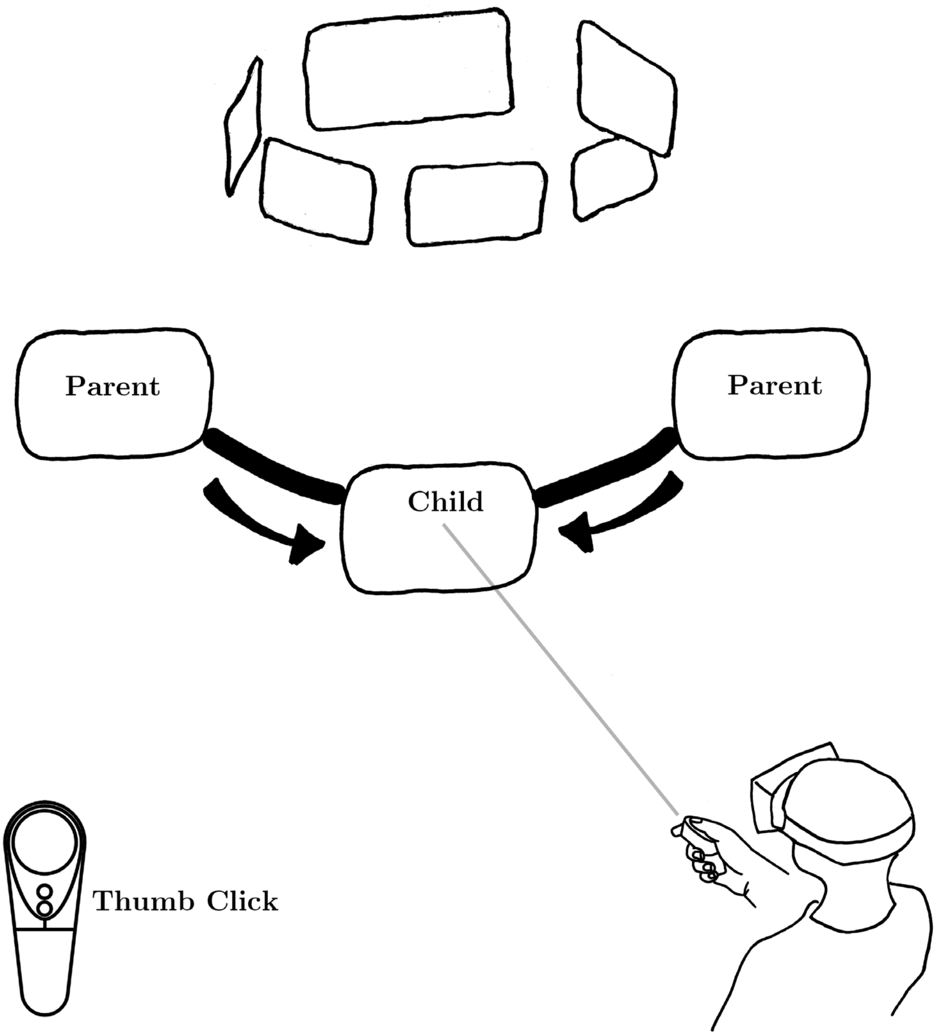


Figure 6.11 Creating relationships between tiles.

To indicate the system state and available interactions, visual feedback can be provided by way of highlighting objects and providing a HUD (Heads Up Display like console or menu). A HUD can be exploited to display available interactions in the current system state to aid user navigation within the state model. For additional feedback, audio cues [115] can act as notifications during interactions. Audible error notifications are important as they allow the user to recover from failed interactions, and when coupled with the other visual feedback elements, guide users to the correct intended interaction. Thus, feedback of the interaction state is provided using a heads-up panel (HUD), locked to the head orientation. It shows actions available to the user in the current interaction state. As the user performs any of the available actions, the corresponding HUD element is

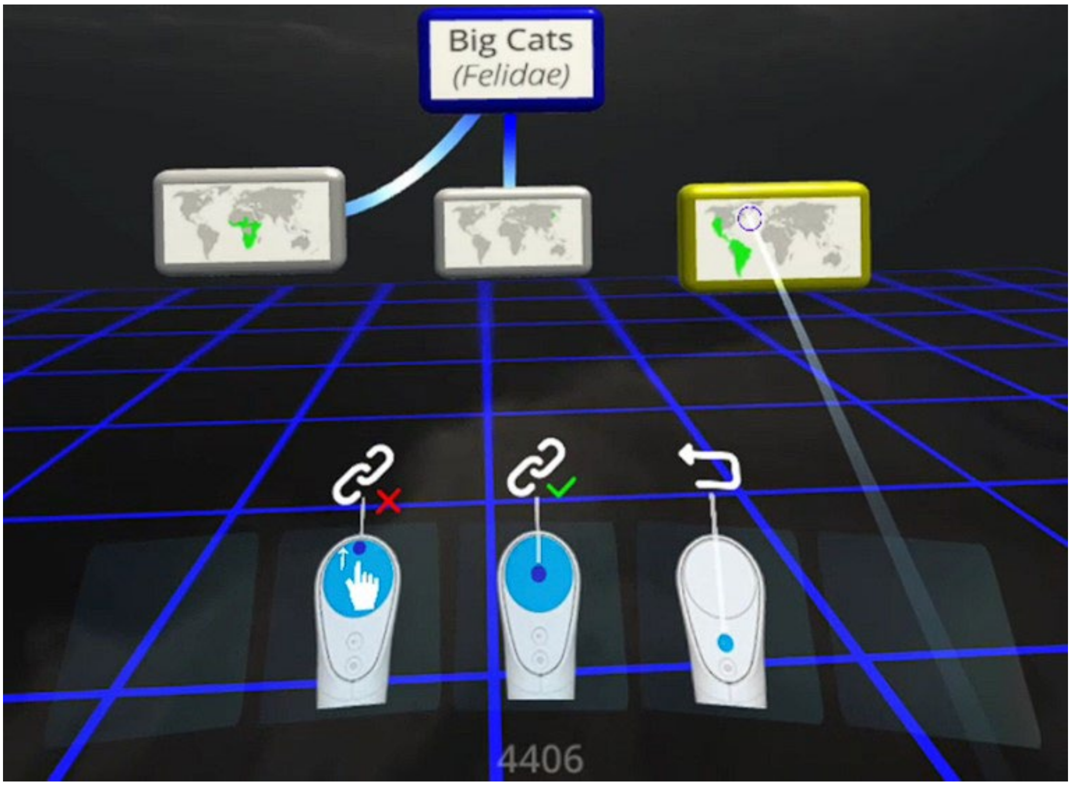


Figure 6.12 Creating a link between two tiles.

Blue indicates the parent tile, yellow indicates a child tile the link can be created to

highlighted to provide visual feedback (figure 6.13). Audio cues and notification error sounds are generated when the user provides controller input which is not mapped to an interaction step in the current state of the interaction model.

The working volume is a 10×10×10 unit cube (1 Unity unit ≈ 1 metre), bounded by a floor with a grid pattern and transparent walls on the remaining 5 sides. A neutral skybox is applied to the entire scene. The tile carousel is located at (0, 2.5, 1). A model representing the physical controller and the controlling hand is displayed on the lower half of the viewing frustum. The model mirrors any change along the 3DoF as well as button clicks and swipes on the touchpad. Further prompts for confirmation of actions and error notifications are implemented. Confirmation sounds are generated on successful selections or manipulation and

Figure 6.14 Ray cast intersecting a tile.

feedback of the interaction state is provided using the heads-up display (HUD) panel at the lower edge of the view. It shows actions available to the user in the current interaction state as well as highlighting the actions as they are performed.

6.4.4 Interaction Workflow and State Model

The interaction techniques discussed above need to be integrated into a single workflow that maps individual controller inputs differently based on an interaction context. To support this, an interaction workflow for VERITAS was developed based on a state-model approach with a goal to provide distinct levels

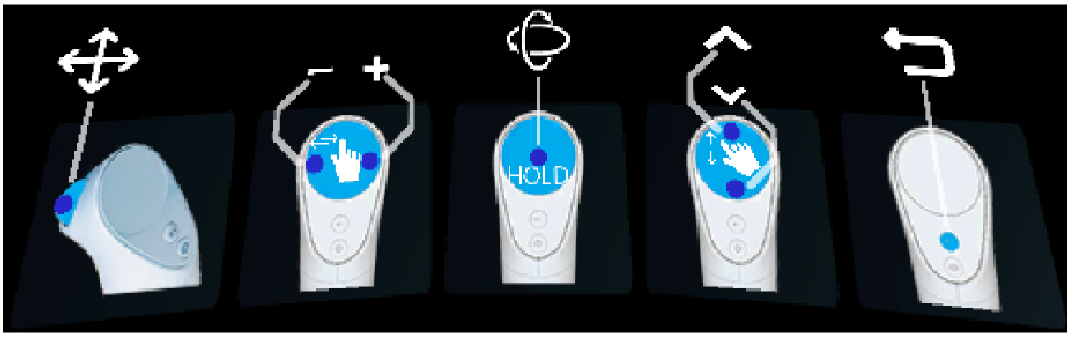


Figure 6.13 Example HUD elements.

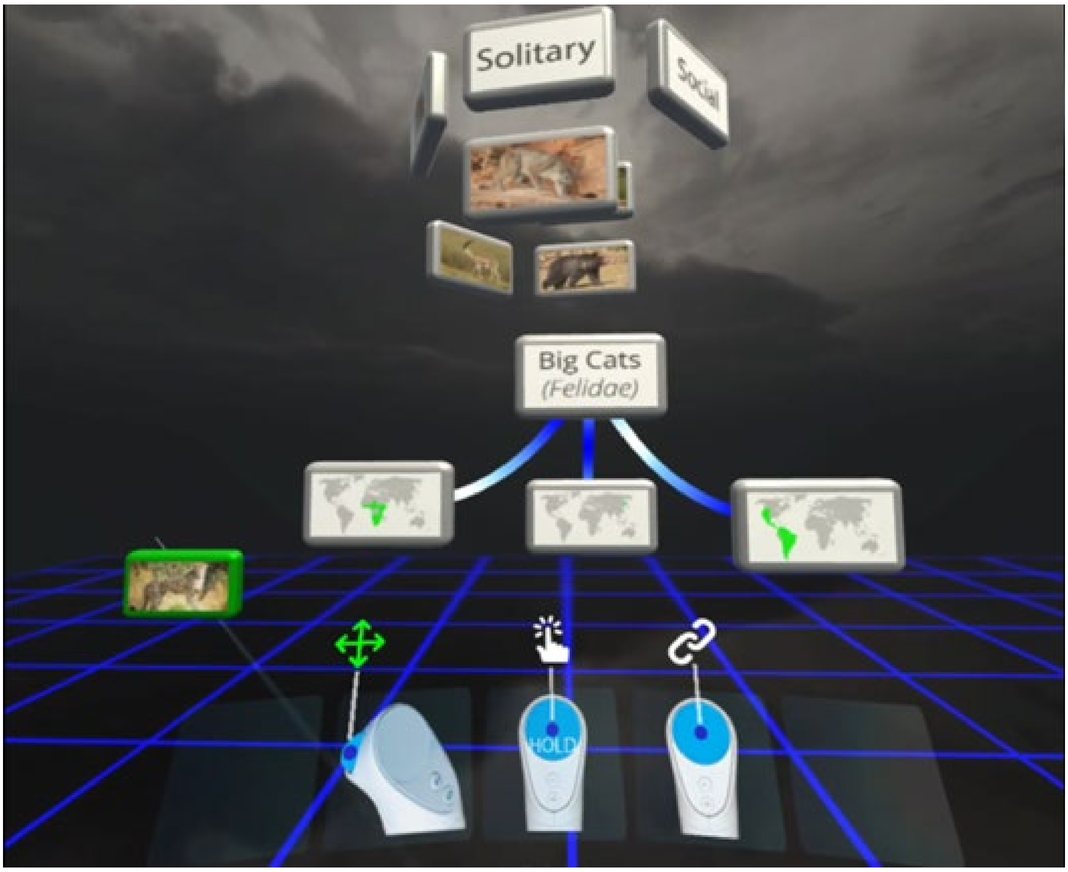


Figure 6.15 Moving a tile out of the carousel (tile highlighted green).

of interaction while keeping the number of states low. The interaction state-model is at most three levels. The HUD is used to provide visual feedback on interaction and display the interactions available in the current context. The start point is a controller in tracking mode waiting for target selection. The tracking is in the form of a ray-cast pointer emanating from the controller model. The direction vector for the ray is determined by the orientation of the controller. When the ray intersects a tile, the tile is highlighted yellow (figure 6.14). Once a tile is selected, the highlight colour changes to green (figure 6.15) and the interactions available for the tile are linked to the controller inputs. The HUD updates to show what actions are available.

The user can perform the default action or enter a deeper interaction mode as required. In all cases, the ‘Back’ controller button reverts the user to the prior state without undoing any previously completed actions. The system provides a full set of audio cues and notification prompts for confirmation of actions and invalid actions.

Certain design decisions were taken based on pilot tests of particular interactions and situations that could arise during the use of the mind map. For example, tiles cannot occupy the same 3D space. If a user tries to position an object into a location which is already occupied by another object, the selected object will slide over, under or to the side of the existing object in the direction of its trajectory.

To aid operation while only using a 3DoF controller, the tile translation action was separated into planar and depth movement. For the planar motion, once selected the user can move the tile up-down and right-left but keep the tile at the same fixed distance from themselves thus moving the tile on a cylindrical curved surface. The decoupled depth motion is available as an independent interaction using a push-pull metaphor through up-down swipe gestures on the touchpad producing movement along the z-axis (away from or towards the user). These interactions are placed orthogonally to the scale interactions (swipe right-left). This placement was intended to accentuate the difference between the two interactions as both produce visually similar outcomes from the perspective of the user.

For rotation, as previously described, the approach of linking the controller orientation to rotation was quickly discarded. In pilot tests, this approach was confirmed extremely difficult to control and angles exceeding 30 degrees were hard to achieve without uncomfortable contortion of the wrist. Instead, the system uses the previous described hysteresis-based implementation. The HUD's feedback was analogous to a crossing-based interactive widget [3] (figure 6.10).

The link creation interaction is tied to tiles. The user can enter the link creation state once a tile is highlighted. The highlighted tile is treated as the parent tile (figure 6.16). The user then points to the child tile and selects it to complete the link between the two. Deletion similarly starts by highlighting the parent tile and entering the delete-link state.

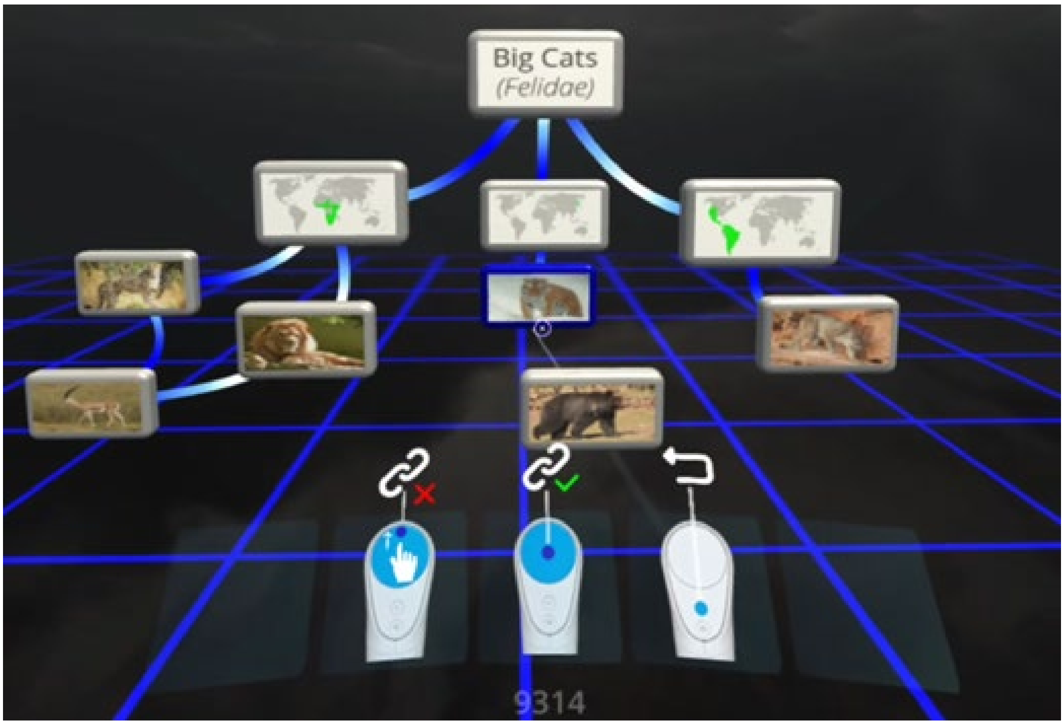


Figure 6.16 creating links between tiles (tile highlighted blue).

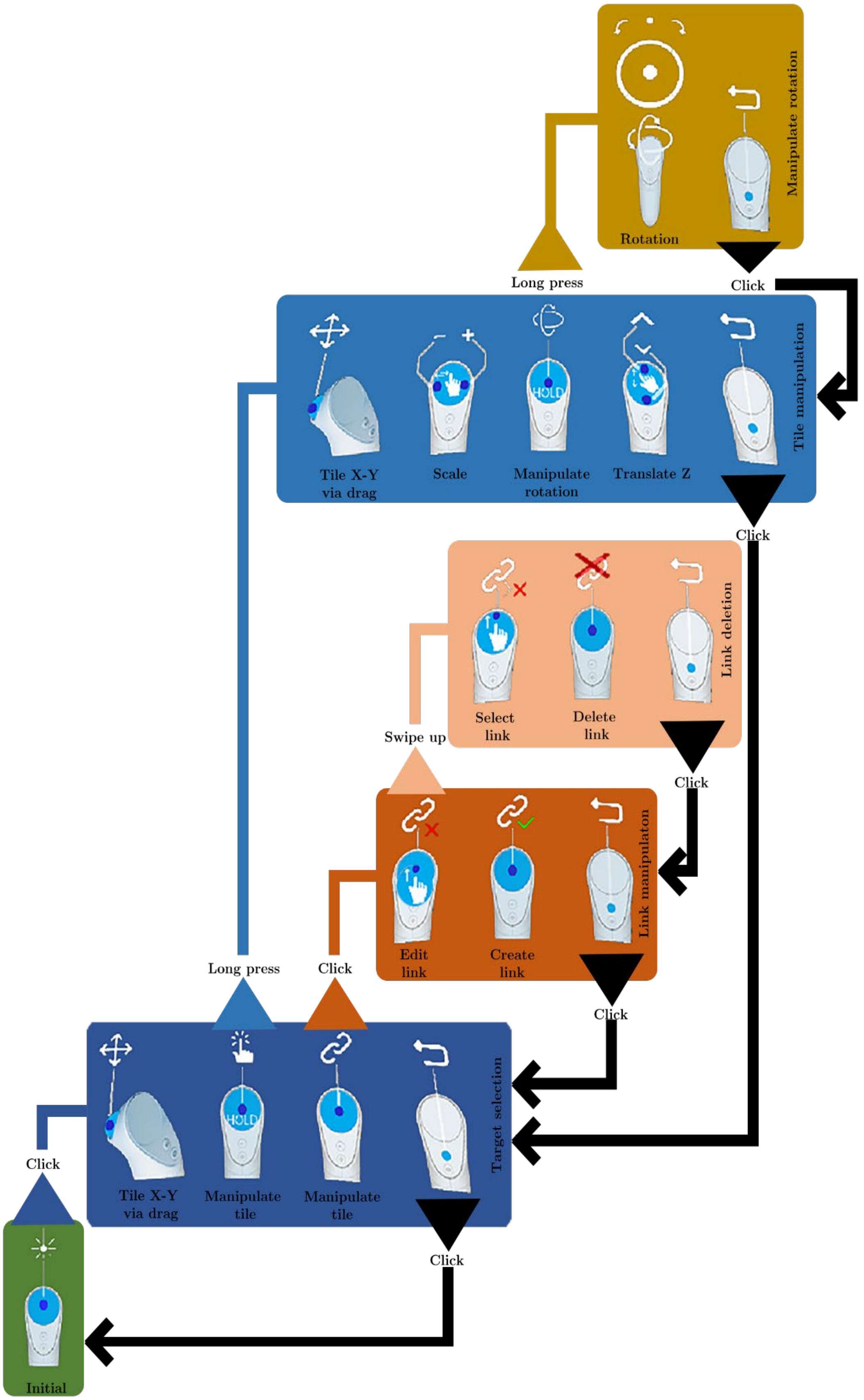


Figure 6.17 VERITAS state model.

6.4.5 Feedback

To indicate the system state and available interactions, visual feedback through highlighting objects is augmented by a heads-up display panel (HUD). The HUD is positioned at the lower edge of the viewport and locked to the head orientation. The HUD displays the available interactions in the current system state and aids user navigation within the state model. As the user performs any of the available actions, the corresponding HUD element is highlighted and animated to provide visual feedback. These HUD elements are shown in figure 6.13. For additional feedback, we provide audio cues [206] for explicit notifications during interactions. A full set of audio cues and notification prompts for confirmation of actions and error notifications is implemented. Confirmation sounds are generated on successful selections or manipulation and error sounds are generated when the successful selections or manipulation and error sounds are generated when the user provides controller input which is not mapped to an interaction step in the current state of the interaction model. Audible error notifications allow the user to recover effectively from invalid interaction inputs, and when coupled with the other visual feedback elements, guide users to the correct interaction input as intended.

6.4.6 Simulator Sickness Considerations

Simulator sickness resulting from visually induced motion is a common and well-studied physiological issue associated with VR [100]. Due to the disparity between the users' vestibular and visual systems, vection is even more pronounced in VR systems that only support 3DoF versus 6DoF through their hardware [128, 139]. VERITAS is a seated experience with no sudden in-application locomotion or change in the position of the user. This alleviates simulator sickness by minimising vection.

6.5 Experiment

The mind mapping task supported by VERITAS is well-known in inquiry-based learning approaches. The individual VR interactions implemented in VERITAS are based on existing literature. However, the motivation of the experiment is to understand if the interaction workflow can allow a user to focus on the mind mapping activity instead of focusing on tool management. Through this study, understanding was also sought to see if the interaction workflow can be learnt quickly enough by novice users. Finally, as an exploration of mind mapping in 3D, to the study sought to identify the emergence of interesting interaction patterns that could inform future work in a collaborative context.

6.5.1 Apparatus

Oculus Go stand-alone VR headset was used for the study. The default factory settings were retained for the purpose of the study, including interpupillary distance, brightness and volume. The headset was configured to store the desired logging information and videos.

6.5.2 Participants

Participants for the study were recruited through a combination of purposive and convenience sampling methods. The recruitment was primarily targeted at individuals within educational institutions, specifically Lancaster University and Blackpool and the Fylde College, to ensure a relevant and informed participant pool. Advertisements and calls for participation were disseminated through institutional mailing lists, bulletin boards, and social media platforms associated with the institutions. The study aimed to include a diverse demographic in terms of age, educational background, and VR experience. Participants were required to be over 18 years of age, with no stipulations on prior experience with virtual reality, ensuring a varied sample in terms of VR familiarity. The recruitment process was governed by ethical guidelines, and all participants provided informed consent before participating in the study.

24 participants over 18 years of age were selected from Lancaster University and Blackpool and the Fylde College to participate in the study. Participants did not require prior experience of virtual reality and there were no stipulated exclusion criteria that would prevent potential participants taking part in the study. The experiment was conducted after acquiring the requisite ethical approvals from Lancaster University.

The participant sample included twenty males, four females, with ages ranging from 18 to 50 years of age. Fifteen of participants were from the 18-25 age-range.

Four participants had no prior VR experience, while one participant had used VR headsets only once before.

6.5.3 Task

Three unrelated topics were chosen to explore the mind mapping exercise – the animal kingdom, a web technology hierarchy and a branching history timeline. The topic, selected via a round robin approach, was presented to the participants as a one-page document containing information related to the topic. Round robin in the context of task selection refers to a method where tasks are assigned or chosen in a sequential, rotating order. This approach ensures a fair distribution of tasks, preventing any single participant from consistently getting either preferable or less desirable tasks. The mind mapping exercise was set up in VERITAS for each of these topics. The exercise consisted of keywords and pictures, with pictures either representing physical entities (i.e., animals, people or objects) or illustrative entities (i.e., maps, actions or symbols). Keywords also included dates and numerical values. An example of a completed activity based on one of the above three scenarios can be seen in figure 6.18.

The tasks consisted of a pre-activity, the main task and a post activity. The pre-activity task and post-activity task were simple instruction tasks that asked the participant to perform interactive actions like scaling a tile and linking two tiles.

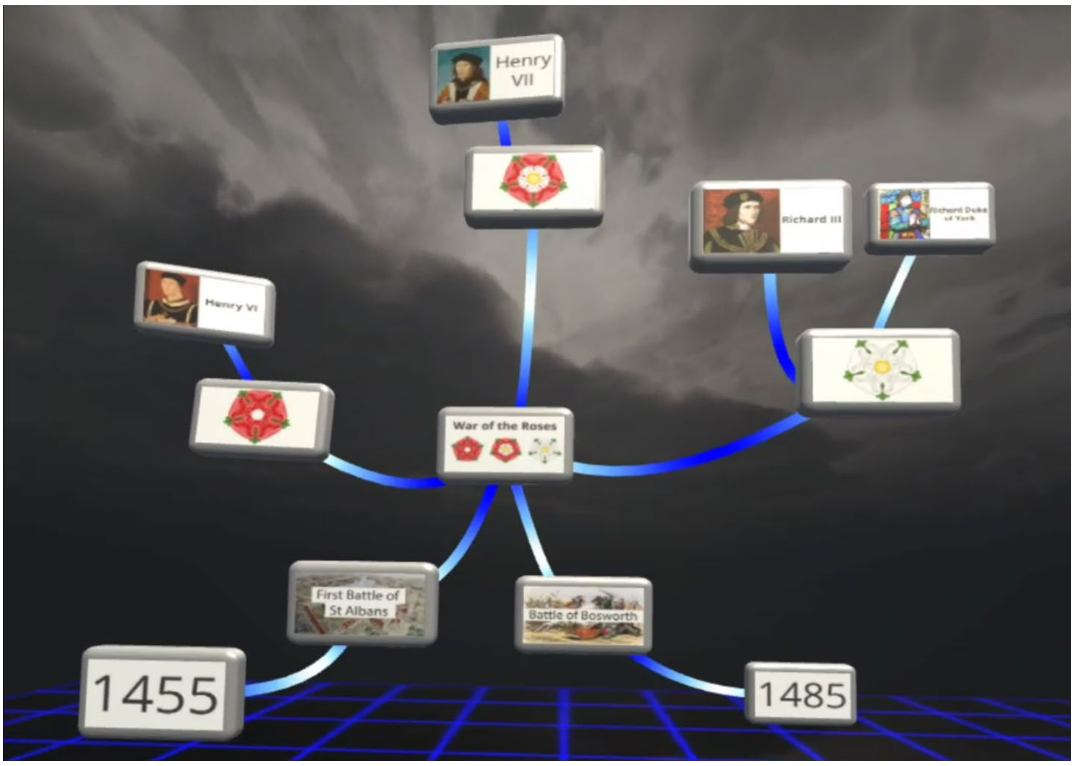


Figure 6.18 A completed mind map activity.

The scenario here is War of the Roses.

The participant had to complete each interaction step before moving to the next task. The required steps were the same for both activities. The main activity consisted of an open-ended exploration of the topic as a mind mapping exercise. The participants were instructed to build the mind map based on the text they had read and reproduce the relationships between the tiles as best as they could. Once they were satisfied with the mind map, they could signal completion.

6.5.4 Metrics

Participants' activities within the system were recorded by way of a video screen capture and system logging that recorded different parameters.

All interactions using the controller were logged along with the context within the interaction workflow. Inputs in an incorrect context were treated as errors and logged. For example, attempting to select a tile when none was highlighted would be treated as an error. Position, orientation, and size of all the tiles was also logged on a periodic basis. The video feed of the VR space was captured to obtain a participant view of what was visible on the headset.

Participants completed a standardised User Experience Questionnaire (UEQ), a standard Simulator Sickness Questionnaire (SSQ) (see appendix B.4) and were given an opportunity to provide open-ended feedback about their experience. The UEQ is a widely used tool for measuring user experience and the quality of applications. The UEQ is designed to elicit a quick and spontaneous response regarding the application or product being assessed and generates statistics for six elements – attractiveness, perspicuity, efficiency, dependability, stimulation and novelty. It also includes a benchmark for comparison against existing applications [222]. A well-designed application is expected to score positively on the UEQ. Scores in the range of +2 represent a very positive result. Negative scores indicate poor user experience with the application. Extreme scores above +2 are rarely returned due to the common occurrence of respondents avoiding answering at the extreme ends of scales. The UEQ has a high internal consistency [217].

6.5.5 Procedure

A repeated measures within-subjects design was used. Each participant was given a pre-selected topic to ensure equal participation for each topic. They participated

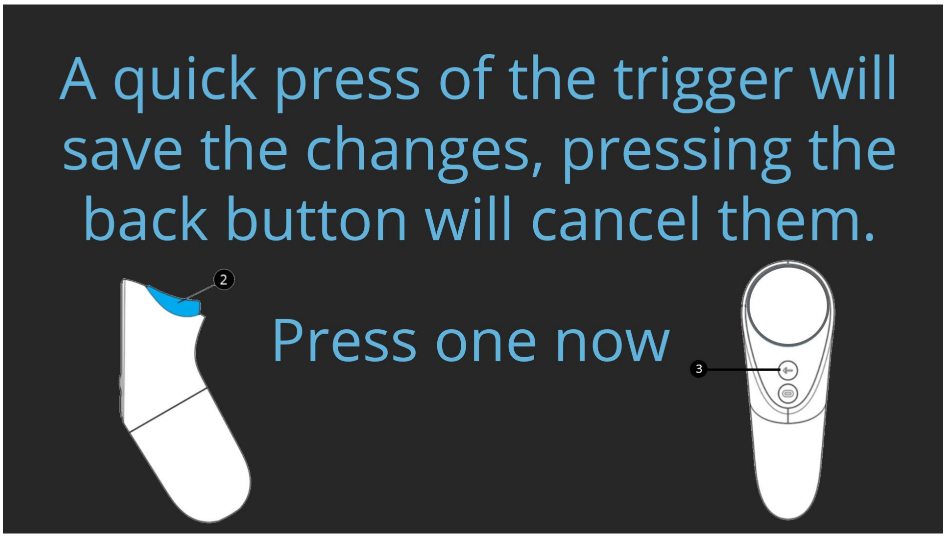


Figure 6.19 Screenshot from the familiarisation tutorial.

in the experiment in one continuous session lasting up to 25 minutes plus 5 minutes to complete questionnaires. Before starting the tasks, the participants undertook a short tutorial inbuilt to the device to familiarise themselves with the headset and controls (figure 6.19). The pre-activity task and the post-activity task were identical in structure. For the post-activity, the helper tips that were provided to assist in performing the interaction (e.g., 'hold button B to select an object' for the pre-activity versus 'select an object' for the post-activity) were removed. This tested the ability of the participants to recall how to effectively interact with the application and undertake all the required interactions without instruction. It was expected that there would be a reduction in interaction errors and a shorter activity completion time for the post-activity versus the pre-activity task.

The UEQ generates statistics for six elements – attractiveness, perspicuity, efficiency, dependability, simulation, and novelty. It also includes a benchmark for comparison against existing applications. However, the benchmark is based on non-VR applications it should be noted that dataset used to construct the benchmark does not specifically include other VR applications. Overall, a well-designed application could be expected to score positively on the UEQ.

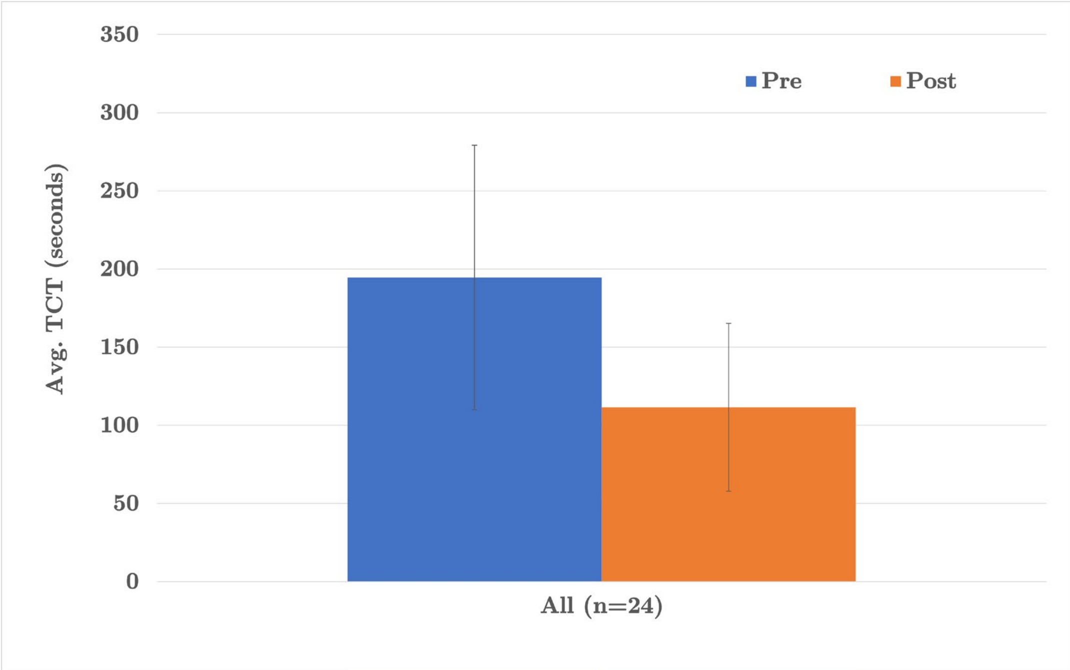


Figure 6.20 Pre and post activity completion times.

6.6 Results

The logged data was analysed for the following: pre-post activity completion times, interaction errors, UEQ, SSQ and free responses. In this study, a p-value threshold of less than 0.05 is employed to determine the statistical significance of results, thus guiding the rejection or acceptance of hypotheses.

6.6.1 Pre/Post Activity Completion Times

For the Pre and Post activity completion times (TCT) an ANOVA with repeated measures was performed. There was a statistically significant difference in TCT between the Pre and Post activity tasks ($F(1,23)=33.07$, $p<.05$) with the Post activity ($M = 111.54$s, $SD = 53.64$s) being completed significantly faster than the Pre activity ($M = 194.54$s, SD = 84.58s).

The individual comparison of Pre and Post task completion times is shown in figure 6.20. There is a clear trend of reduced completion time in post activity tasks.

6.6.2 Interaction Errors

The error rates for each interaction category (translate, select, rotate and link) were analysed and using an ANOVA with repeated measures test, no significant difference between the error rates for both pre-activity and post-activity tasks was found. Overall, the error rates were observed as very low (0.31% for pre-activity and 0.68% for post-activity) in all categories.

6.6.3 Main Activity Analysis

It was observed that every user successfully created a clear and recognisable mind map with complete relationships and good spatial positioning, including in the z-axis. They made full use of all the available interactions to manipulate the tiles and build their mind map. It was observed that completed mind maps followed one of three styles – radial, tree or star (see figure 6.21), with radial being the most common style with twelve occurrences, seven for tree and five for star.

Quantitatively, the results analysis also looked at error rates, how users utilised the 3D space and how long they took to complete the main activity task. It was noted that most users made use of the z-axis in some dimension ($M = 3.58$ unity units, $SD = .88$) and the overall error rates were low ($M = 0.97\%$ of all interactions). The average time to complete the main activity task was 398s with no outliers. The analysis explored the possibility that the topic selected for the mind map activity could present itself as an experimental confound. To eliminate this, the analysis used one-way ANOVA, with 'topic' as the between-subjects factor for analysis against error rate, activity completion times and tile movement and found no statistically significant difference to suggest that the topic was a factor.

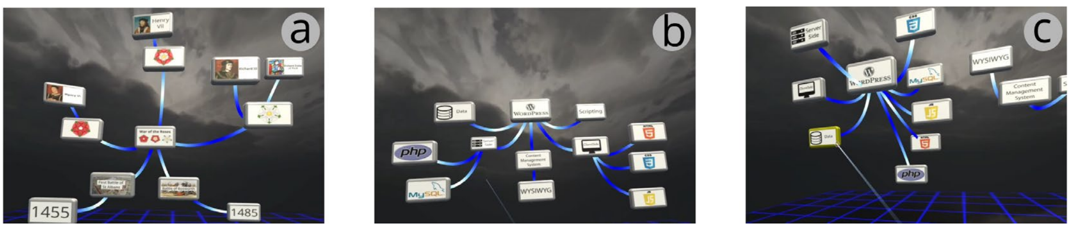


Figure 6.21 Hierarchical organisation styles used by participants.

(a) Radial, (b) Tree and (c) star.

6.6.4 UEQ

The UEQ is provided with an automated analysis tool for generating results. Results from the tool are reported here. The participants scored VERITAS high in terms of attractiveness, stimulation, and novelty (see figure 6.22). The scores for perspicuity, efficiency and dependability were also positive but lower. Expert VR users could bias the Hedonic Quality metric of UEQ. However, previous work [138, 217, 259] does not discuss the bias as a factor affecting UEQ scores for familiar users (mere-exposure effect versus expertise). Since none of the participants identified as "Expert", the question of bias is approached in line with previous work.

6.6.5 SSQ

Responses to SSQ showed no notable increase in discomfort or any form of nausea. Only one participant noted an increase in discomfort (pins and needles in hands).

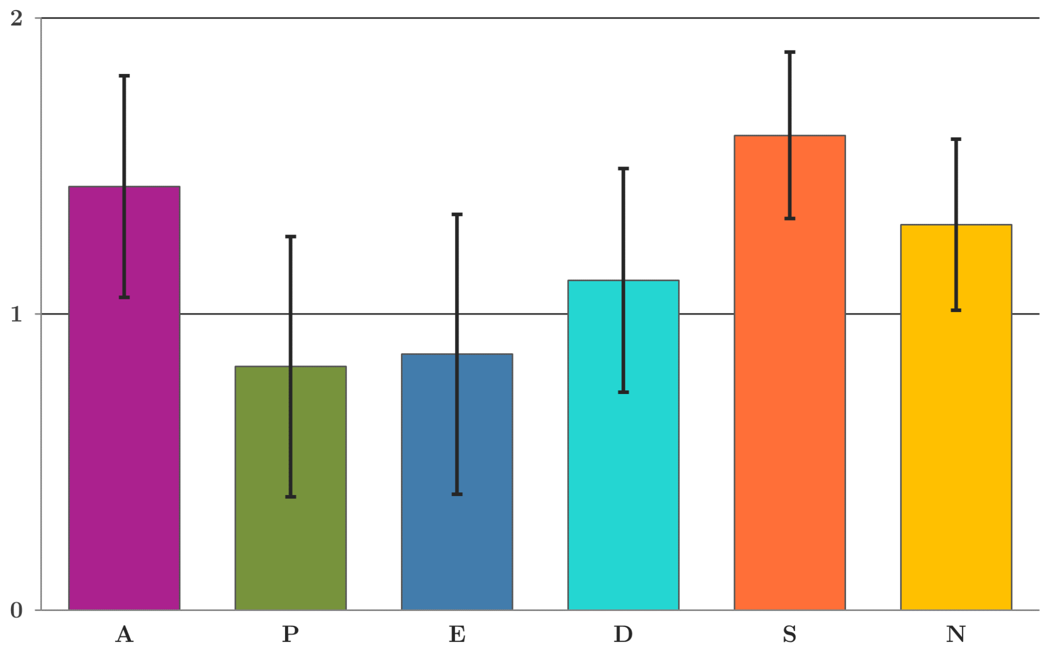


Figure 6.22 UEQ Metrics

A = Attractiveness, P = Perspicuity, E = Efficiency, D = Dependability, S = Stimulation, N = Novelty. UEQ scale range is [-3, 3] but is truncated due to absence of negative values

The same participant noted existing issues with fine motor control for their thumb.

6.6.6 User Responses

The participants were asked to reflect upon their experience in an open-ended format. Seven participants noted that the HUD location was too low in the viewport, and one didn't notice the HUD at all. Two participants stated they felt there were too many steps required to delete a link. Three participants stated they would like to be able to select multiple objects and move them as a group.

Given the limited number of interview responses, a full thematic analysis was not feasible due to insufficient data. Instead, the qualitative data collected from the interviews was used primarily for minor triangulation purposes. For instance, some interview responses were used to provide context to specific quantitative findings, such as low SSQ scores. An example of this triangulation was observed in instances where low SSQ scores correlated with participants indicating minor motor movement issues. This approach allowed for a nuanced understanding of certain data points, albeit on a smaller scale than initially planned. The qualitative responses, though limited, offered insights that complement the quantitative data and provide a more rounded perspective on the study's findings.

6.6.7 Visualisation

Using the logged tile position data, 3D visualisation was created to explore tile movements (figure 6.23) shows a composite of five participants tile movements) during the main activity. The plot displays the movement of every tile for each user. The time (t) spent by a tile at each location is represented by a shape enclosed in a sphere of diameter = log10t. This plot shows that participants used the full space afforded by the virtual environment for creating a mind map.

6.7 Discussion

The aim was to investigate if a simple, yet usable interaction workflow could be developed for interacting with a mind map in VR.

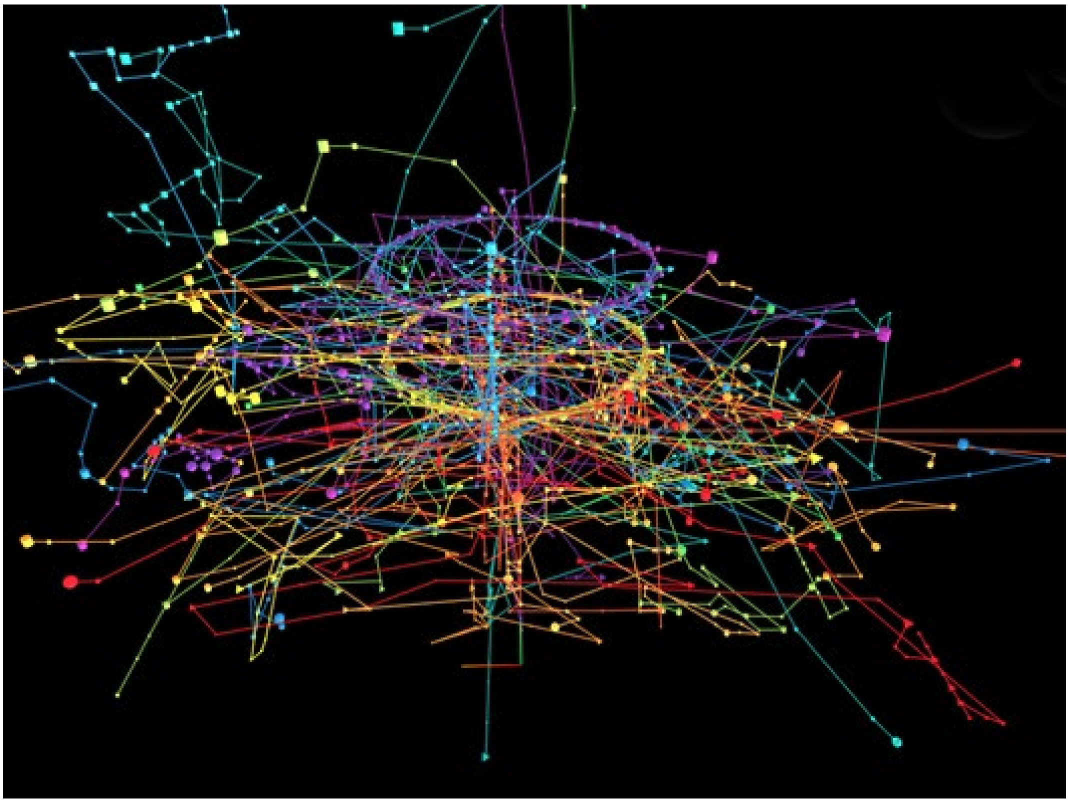


Figure 6.23 Visualisation of tile movements made by a user.

6.7.1 Usability of VERITAS

The quantitative analysis of the Pre/Post Activity tasks is the first indicator for the usability of VERITAS. The analysis find an expected reduction in task completion times (TCT) for the post-task. Apart from learning effect, the positive observation of low error rates indicates that the participants were able to work with the interaction metaphors without extra effort. If the interaction metaphors were harder to recognise or recall, the absence of the helper prompts in the post-activity would have affected the TCT or error rates, which was not the case. All users completed the main activity to a reasonable standard of completeness and quality, indicating that all the essential interactions are in place.

The main activity and completeness of the resulting mind maps demonstrated that the participants were able to understand and use the state-model for the interaction workflow with relative ease. Even if some interactions (like rotation) were placed deeper than the default state, the participants navigated the states without difficulty. This state-model is supported by low-cost 3DoF controllers that are commonly available. However, if 6DoF controllers become commonplace, the state-model can be mapped to the controller inputs with minimal modifications.

The UEQ provides further insight into the usability. The strong results for attractiveness and novelty metrics would be normally expected for a well-designed VR application. The stimulation metric indicates higher motivation to continue using the product. This observation is particularly important as situational interest is essential to inquiry-based learning and strengthens the argument for performing mind mapping exercises in VR. Perspicuity, efficiency, and dependability metrics are positive though not as strong as the prior metrics. The perspicuity metric measures the pragmatic qualities and learnability of the application. The metrics indicate that users found the application to be a different learning experience than usual.

The SSQ responses indicate that the design choices did not result in increased discomfort while using the application. The feedback from the participants were mainly positive. One participant mentioned that the interactions appeared to be a blend of intuitive versus learnable. The participant with high select and rotate errors mentioned that they had an issue with fine-motor control of their thumb. This led to accidental clicking of the touchpad when trying to swipe, causing selection and rotate errors. The participant also noted that they were able to recover from the accidental inputs and continue successfully without much effort. This raises a point for consideration about accessibility of controllers but is beyond the scope of current research.

6.7.2 Mind mapping in VR

The motivation for VERTIAS was to identify a suitable interaction workflow to support creation of mind maps in VR. The study also attempted to see how users would make use of the 3D space available to them for organising the information. The video analysis and the tile position visualisations showed a very good use of 3D space with each participant producing a clearly identifiable mind map in one of three styles. Participants made ample use of the spatial positions, logging interactions to move the tiles back and forth along the Z-axis (depth interaction). This can be visualised in figure 6.23. They also focused on the orienting the tiles to suit a view that they preferred. The use of the Z axis suggests that mind mapping in VR may offer advantages over traditional 2D implementations.

It is suggested that virtual 3D environments can improve activities such as mind mapping by providing an enhanced spatial representation. In a virtual 3D environment, users can create and visualise mind maps in three dimensions, which offers a more comprehensive view of the information and its connections. This can lead to a better understanding of complex relationships and concepts. The immersive nature of virtual 3D space can also increase engagement and focus. As users are more involved in the activity, they may be more inclined to explore and experiment with different ideas, leading to a deeper understanding and more creative solutions. In addition, virtual 3D space allows for more intuitive and natural interactions with the mind map elements. Users can manipulate and arrange nodes and connections in ways that are not possible with traditional 2D applications. This freedom of movement and interaction can lead to more efficient and effective organisation of ideas.

6.7.3 Design Discussion

The interaction workflow of VERITAS is designed for use with low-cost 3DoF controllers. While the studies ran on an Oculus Go headset, VERITAS could be easily ported to a low-fidelity smartphone setup (e.g., Cardboard) making it even more accessible or to the Oculus Quest for increased interactions possibilities afforded by a 6DoF headset and controllers.

While the current scope of VERITAS is a single-user mind map activity, the leap to a collaborative mind mapping application is obvious. When collaborative mind mapping is carried out on tabletops, the collaborative exercise results in specific patterns of communication and strategies for managing conflict [113]. These arise due to the need to control shared pieces of information (e.g., tiles) and their relative positions. Users do try to move objects at the same time; however, users will relinquish control of an object if they perceive another's actions is correct (termed collaborative interplay). Collaborative mind mapping in VR has the opportunity to support richer interactions and collaborations since the independent headsets can support 'one-world, multiple perspectives' for the task. Collaborative strategies involving shared workspaces and personal workspaces

[120] can be applied to VR with relative ease while continuing to foster communication between the peers. A key to enabling effective collaboration within VR is the need for communicating system state of all objects (i.e., an item being moved) to all users and that the users' actions are apparent to all other users (i.e., gaze directions, pointer direction, if they are modifying an object).

With the usability of VERITAS established, exploration of user behaviours within the application is required to develop the application further to support collaborative learning. There is also the obvious question - Does learning indeed occur within a VR mind mapping application (and how to measure such learning)? The current design of VERITAS provides a baseline system that can be expanded in the future and trivially instrumented to further understand collaborative interactions as well as evaluation of learning effectiveness and user mind mapping strategies.

6.8 Future work

It would be beneficial to explore the potential for collaboration within virtual 3D environments. Multiple users could work together in a shared virtual environment, employing communication strategies and cooperation on the mind map. This collaborative aspect could lead to more diverse perspectives and richer discussions. It would also be interesting to test if virtual 3D environments can help users retain information more effectively. The combination of visual, spatial, and interactive elements in a virtual 3D environment may contribute to better memory encoding and recall, as it engages multiple senses and cognitive processes simultaneously.

6.9 Conclusion

This study provides insights into the use of low-cost VR devices for complex educational activities, specifically addressing RQ1, RQ1.1, and RQ1.2. It demonstrates that low-cost VR devices, despite their limited input controls, are capable of supporting engaging and interactive educational activities such as mind mapping, directly answering RQ1. The effective and usable interaction workflows developed for the VR mind mapping application VERITAS, along with the minimal interaction errors observed, align with RQ1.1, showcasing how specific interaction paradigms and methods can be utilized in VR to create engaging educational experiences.

Furthermore, the study's exploration of mind mapping in VR contributes to answering RQ1.2, regarding the use of VR for domain-agnostic learning. The participants' utilization of the 3D space in VR to organize and manipulate mind maps illustrates the potential of VR in supporting learning activities that are not bound to a specific domain. This aspect of the study shows how VR can be used to enhance cognitive processes involved in learning, such as spatial reasoning and visual representation, which are crucial in domain-agnostic learning environments.

The study's findings highlight the potential of low-cost VR devices in enhancing educational experiences, not only by making them more engaging and interactive but also by supporting domain-agnostic learning. The successful implementation of mind mapping in VR, as evidenced by the effective use of 3D space and the learnability of the application, underscores the advantages of VR in educational settings. This suggests that VR can be a valuable tool in education, offering unique opportunities for learning that go beyond traditional 2D applications and extend into versatile, domain-agnostic educational experiences.

Chapter 7

User Behaviours and Mind mapping Strategies

7.1 Introduction

Having confirmed that a usable mind mapping application could be created on low-cost VR devices in the previous chapter, it considered how the VERITAS application artifact could be expanded to include collaborative elements. This additional study pertains to designing for collaborative VR by observing user behaviour by emphasising, recognising and categorising user behaviour in order to obtain insight into how users interact with VR. By classifying user behaviour, developers can find patterns and themes associated with engagement and learning outcomes, enabling the creation of more effective and engaging VR applications for collaborative learning. By designing VR applications with collaborative interactions in mind, designers may create immersive and engaging learning experiences that facilitate user collaboration and knowledge exchange.

After reviewing the Computer Supported Collaborative Work (CSCW) research, it was challenging to identify a set of recommendations on how to proceed. The open question for VR-based mind mapping, given the additional spatial dimension available for use, is how the environment can better support the users engaged in reflective learning. By identifying and understanding individual behaviours associated with the information organisation process, the role of VR in supporting this process we can refined. The individual behaviours, resulting from the users' information organisation strategy, can better inform the design of applications about the affordances necessary in a collaborative environment. This would result in developing better VR interactive systems for reflective tasks in peer-based learning (paragogy).

To explore this aspect, this chapter re-analyse the data collected in chapter 5 through this different lens. This was possible as VERITAS was instrumented from the outset to collect data concerning various usage perspectives. This allowed VERITAS to achieve the goal of using the application for multi-faceted studies through an iterative approach.

7.2 Background

Recognising individual strategy is a key element to managing conflict, a prime criterion in collaborative spaces [98, 181]. CSCW research has shown that territoriality emerges during collaborative working in groups [210, 223]. Additional research [252] has identified the need to support users in their specific way of working during a collaborative activity. When collaborative mind mapping is carried out on tabletops, the collaborative exercise results in specific patterns of communication and strategies for managing conflict [113]. These arise due to the need to control shared pieces of information (e.g., images, keywords, relationships) and their relative positions. Researchers have proposed hardware solutions to address the challenge of supporting territoriality and the resulting personal and shared spaces [120, 146, 166]. A system mediated approach is essential for any collaborative activity involving mind maps in VR and even AR. Designers of collaborative mind maps in these mediums need to consider how their application will separate the personal and shared workspaces and mediate personal strategies. These systems aim to prevent suppression of an individual strategy or favouring one strategy over the other, which can occur either through system design or other users dominating the activity. The alleviation of this risk becomes critical in an educational setting since an unsupported user could switch to being a passive learner rather than an active one, negating the benefits of paragogy. However, there is a gap in literature that identifies or defines what kind of individual strategies exist.

The research question is thus twofold. Firstly, to identify behaviours or strategies that emerge when participants construct a mind map through a VR mediated application. Secondly, if unique behaviours or strategies emerge, what are their implications when considering collaborative mind mapping in VR? This chapter answers these questions by conducting an exploratory study to identify and quantify the presence of individual behaviours or strategies in a learning setting using VR-mediated mind mapping.

7.3 Motivation

The motivation for this chapter is to understand how students' learning behaviours and strategies emerge in a VR-based mind mapping environment. These learning behaviours manifest during the pedagogical activity of inquiry-based learning through reflection. Such reflection can be mediated through a VR application, designed to support learners engaged in inquiry-based learning through tasks like mind mapping. As an emerging application space, there are very few VR mind mapping applications that support interactive reflection and information organisation. At the time of the study, only two commercial products [48, 262] were identified. While these products can help with the qualitative aspects of the study, they do not support the instrumentation necessary for the quantitative aspects. This chapter uses an alternative proof-of-concept VR mind mapping tool VERITAS [237] as it allows data collection of user interactions in real-time and via log files. The useability of this tool is validated in a previous study [238] and the study aims to build on this previous work to contribute to the understanding of mind mapping in VR as a whole.

7.4 Methodology

A mixed-methods research technique was used which comprised of observing user behaviour, recording interactions, and applied thematic analysis to classify and interpret the observed behaviours. This methodology is frequently employed in domains including human-computer interaction (HCI) and educational research. Participants were instructed to perform a task within VERITAS while their interactions were recorded. The acquired information included quantitative data, such as task completion time and precision, and qualitative data, such as observed and nonverbal behaviour. Observed behaviours were then categorised based on the patterns and themes that had been detected. The results of the investigation were evaluated in order to form inferences regarding the observed behaviour. The analysis of the results involved comparing the observed behaviours to existing literature and drawing conclusion about the way the tasks were completed. This methodology is a strategy to data gathering and analysis that enabled a thorough understanding of user behaviour and interactions within the VERITAS artifact.

7.5 Measures

7.5.1 Video Coding

The video feed of the VR space was captured to obtain a participant view of what was visible on the headset. Video coding analysis of these videos was carried out by two independent coders. The coders looked for patterns that indicated a preferred strategy of organisation of information in the mind map. The video coding analysis of the task revealed a between-subjects factor. All relevant measures were then analysed as a between-subjects design.

7.5.2 Task Metrics

VERITAS logs each controller input along with the relevance to the state-model of the interaction workflow. If the controller input was invalid for the current state, it was logged as an error. The position and size of all tiles are logged at a periodic interval. These logs allowed us to extract useful data like task completion time, error rates and position tracking for tiles.

7.5.3 Questionnaires

Participants completed a standardised User Experience Questionnaire (UEQ) [138] designed to measure user experience of interactive products, a standard Simulator Sickness Questionnaire (SSQ) and were given an opportunity to provide open-ended feedback.

7.6 Results

The quantitative analysis of the collected data was performed using SPSS 26. In this study, task completion times (TCT) have been normalised as a percentage of overall TCT to allow for a fair comparison between different groups/categories. After normalisation, the adjusted percentages were used for subsequent analyses and presentation of result, with the normalisation process described where appropriate.

In this study, a p-value threshold of less than 0.05 is employed to determine the statistical significance of results, thus guiding the rejection or acceptance of hypotheses.

Figure 7.1 *Grouping* strategy .

(left) User ordering tiles first before, (right) creating links when all tiles are roughly in position.

*Note, illustrations are two separate participants employing the same strategy

7.6.1 Cohort Identification

A thematic analysis [34] of the twenty-four task videos was performed. The objective was to identify distinguishing features which could be interpreted as differing mind mapping strategies. Two coders looked at the way the participants interacted with the tiles and how they approached the mind map creation activity. This helped identify two distinct behaviour patterns. The first approach was named *grouping*. A *grouping* participant dragged tiles out of the carousel and organised them into small, related groups until the carousel was empty (figure 7.1). They then rearranged the tiles spatially before creating the links (relationships) between the tiles. The second approach was named sequential. A sequential participant dragged a pair of tiles from the carousel and immediately created a link between them, before dragging another tile from the carousel that was related to the first two tiles and created a fresh link (figure 7.2). This cycle was repeated tile by tile until the mind map was complete and the carousel empty. These observations were made independently during the video coding step by the coders and there was no disagreement about the code (*sequential* or *grouping*) assigned to each participant creating two distinct cohorts. The styles were distinct, and no blended style was observed.

To characterise the cohorts quantitatively, the coders recorded the timestamp when a clear gestalt grouping of three or more similar tiles (e.g., cats, computer languages or battles) emerged in the video. Next, the timestamp from the system logs we extracted to identify the point where the participants created their first link. These event timestamps for link and group creation were normalised using the individual task completion time (100×event_ts/activity time), allowing us to compare the relative position of the event (link/group) within the overall activity. The timestamps were tested using the intraclass correlation coefficient (ICC) test with a consistency, two-way random effects model. A high degree of reliability was found between the two coders' measurements. The average measures ICC was .967 with a 95% confidence interval from [.924, .986], $F(23,23)=30.42$, $p > .001$.

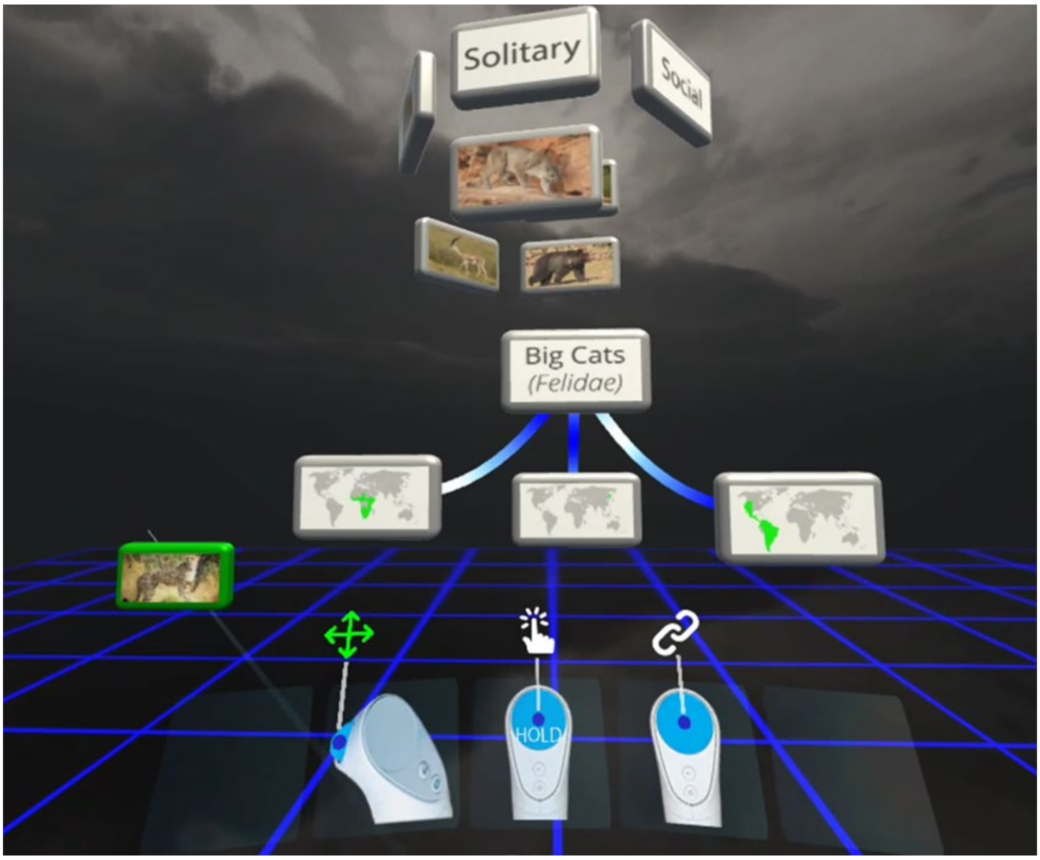


Figure 7.2 *Sequential* strategy.

User dragging tiles from the carousel one at a time and immediately linking the tiles

To compare if there was any difference between the sequential and grouping

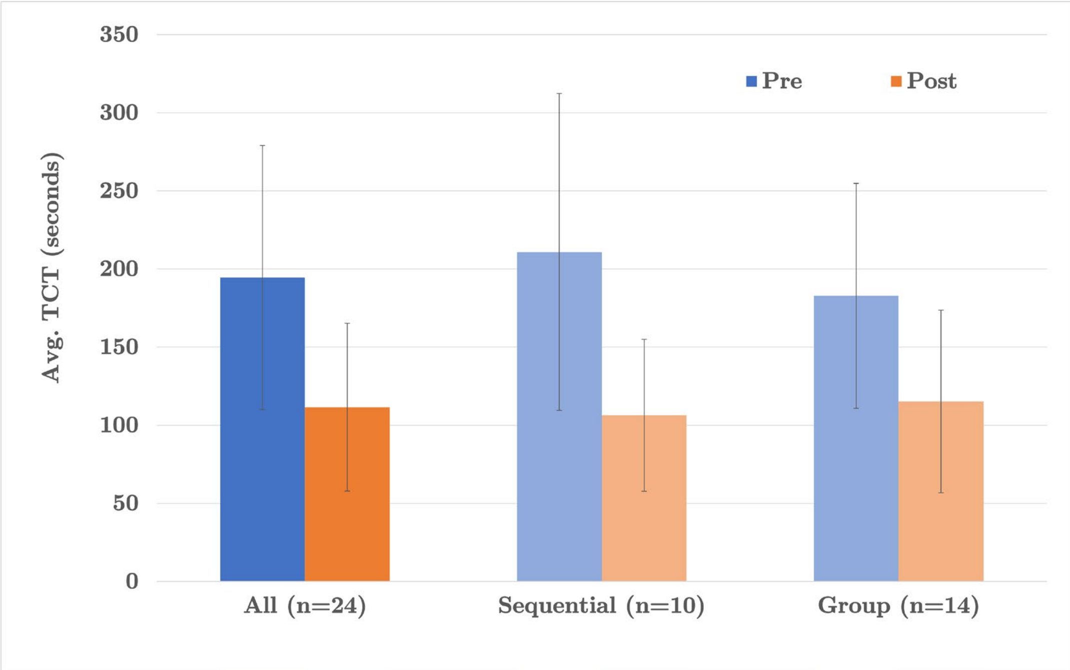


Figure 7.3 Pre and post activity completion times.

cohorts for the main activity and Pre and Post task completion times (TCT) a two-way ANOVA with repeated measures in one factor was performed. There was no statistically significant two-way interaction between cohort and main activity TCT, F(1,23)= 2.37, $p > .32$. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the sequential cohort (M = 337.00s, SD = 149.40s) was not significantly different than the grouping cohort (M = 442.21s, SD = 174.69s). The main effect of activity showed that there was no statistically significant difference in TCT between the Pre and Post activity tasks (F(1,22)=1.628, $p > .215$). The individual comparison of Pre and Post task completion times by cohort are shown in figure 7.3.

Next, a one-way ANOVA, with between-subjects factor as 'cohort' was used for analysis of the two events - first group-creation time (normalised) and first link-creation time (normalised). A statistically significant difference between the two cohorts was found for both first group creation ($F(1,23)=15.99$, $p<0.05$) and first link creation ($F(1,23)=4.59$, $p<0.05$), thus quantitatively validating the visual observation that the two cohorts had different strategies for building the mind map. The *grouping* cohort created the first group significantly earlier ($M = 0.17$, $SD = .10$) as compared to the *sequential* cohort ($M = 0.43$, $SD = .22$) in the activity timeline. Conversely, the *sequential* cohort created their first link significantly earlier ($M = 0.25$, $SD = .11$) compared to the *grouping* cohort ($M = 0.40$, $SD = .20$) (figure 7.4). Therefore, the factor of cohort informed the further analysis of the task metrics. The possibility that the topics selected for the mind map activity could present as an experimental confound was explored. The above tests we rerun with topic as a factor and found no statistically significant difference to suggest that the topic was a factor.

7.6.2 Cohort Based Analysis

Having established the two mind mapping strategies, the quantitative metrics was analysed with the additional between-subjects factor "Cohort" with two values,

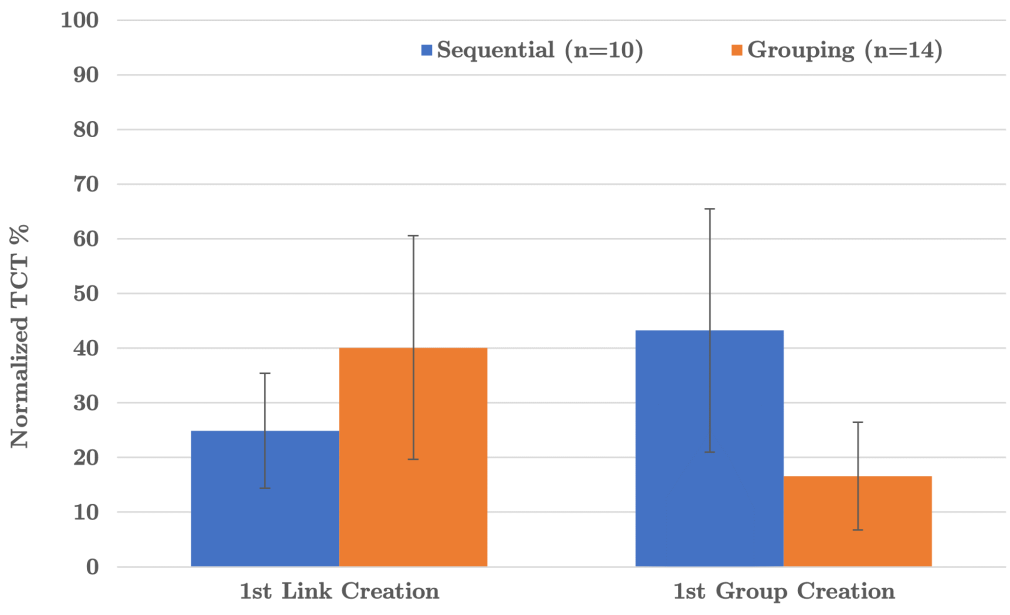


Figure 7.4 Cohort comparison for 1st Link and 1st Group Creation.

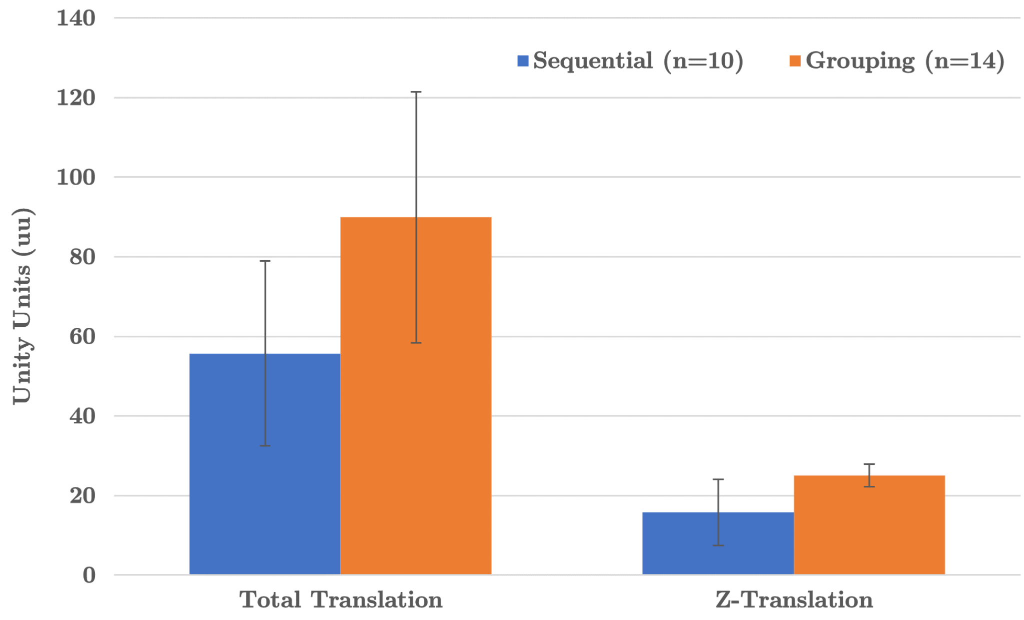


Figure 7.5 Cohort comparison for tile movement.

"*Grouping*" and "*Sequential*". For all the following tests, one-way ANOVA, with between-subjects factor as cohort was used.

The spatial volume usage was analysed using three different metrics. A bounding box volume was calculated for the entire activity per user using the maxima of positions of all the tiles along each axis in Unity units (uu3). There was no statistically significant difference between the *sequential* cohort and the *grouping* cohort means as determined by one-way ANOVA ($F(1,23)=2.461$, $p > .131$) for bounding volume. Both groups made similar use of the volume which extends beyond the default starting viewport volume. This matched the observations during the video coding analysis step. Next, analysis looked at how much tile movement was performed by the user. Two values were calculated per user: a) the total distance travelled by all tiles (D); b) the distance travelled along the z-

Table 4 Quantitative Metrics

Metric	*M Sequential*	*M Grouping*	Significance
First Link	0.25	0.40	p<0.05
First Group	0.43	0.17	p<0.05
Mean TCT	337s	442s	NS
Bounding volume	66uu^3	95uu^3	NS
Total Translation	55.7uu	89.8uu	p<0.05
Z-Translation	15.8uu	25uu	p<0.05
Interaction Errors	11.4	13.9	NS

axis only (Z). Here, analysis found statistically significant differences for total distance (F(1,23)=8.39, $p < 0.05$) and also for z-axis traversal (F(1,23)=5.16, $p < 0.05$). In both cases, the *grouping* cohort moved the tiles more (MD = 89.8uu, MZ = 25uu) than the sequential cohort (MD = 55.7uu, MZ = 15.8uu). These results are tabulated in Table 4 and figure 7.5 for total distance and z-axis movement.

Using the logged tile position data, a 3D visualisation was created to illustrate tile movements (figure 7.6 shows a composite of five participants in each cohort respectively). The plot displays the movement of every tile for each user. The time (t) spent by a tile at each location is represented by a shape enclosed in a sphere of diameter = log10t. The visualisations match the tile related quantitative metrics and qualitative observations.

Analysis also looked at gender to see if there was an obvious discrepancy or alignment to the aforementioned cohorts. It was found that for the *sequential*

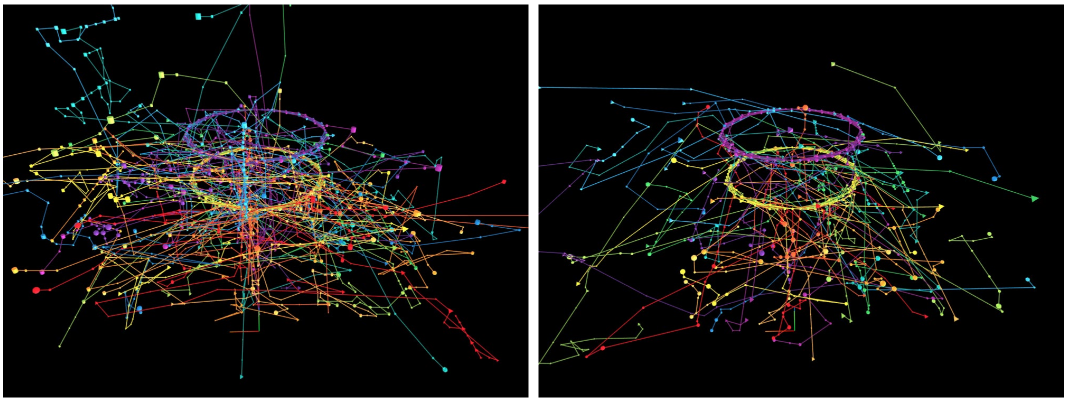


Figure 7.6 Visualisation of tile movement

grouping cohort (left) and sequential cohort (right).

cohort 20% were female and 80% were male and for the *grouping* 14.3% were female and 85.7% were male. This split did not warrant further statistical analysis and there appears to be no obvious gender-based differences in the result. Similar observations were made in respect of the age ranges of the participants and prior VR experience, with no obvious differences emerging.

It was observed that completed mind maps followed one of three styles – radial, tree or star. These styles were spread across both cohorts (*grouping* and *sequential*), with radial being the most common style with twelve occurrences, seven for tree and five for star. These styles are consistent with completed mind maps seen in other traditional mind mapping activities. The analysis found no statistically difference between grouping for their mind map style.

7.6.3 Interaction Errors

Error rates were analysed for each interaction category (translate, select, rotate and link). Overall, it was observed that the error rates were very low (0.97%) in all categories. Using an ANOVA repeated measures test, no significant difference between the error rates for each cohort was found. Using topic as a factor, no significant difference in error rates emerged. The only notable outlier was one participant who logged higher select and rotate errors (17 and 30 errors respectively).

7.7 Questionnaires

7.7.1 UEQ

Analysis was run to see if the strategy in creating the mind maps (i.e., *sequential* or *grouping*) influenced user experience. The data gathered in the previous VERITAS study in Chapter 6 was reanalysed to gain insights into how the two groups differed. The automated tool provided with the UEQ was used in addition to bespoke tests to generate analysis against the questionnaire results. Results from the tool are reported here. One-way ANOVA, with between-subjects factor as cohort was used. A statistically significant difference for the attractiveness was found ($F(1,23)=12.58$, $p < 0.05$) and stimulation ($F(1,23)=6.81$, $p < 0.05$) metrics between the two cohorts. For attractiveness, the sequential cohort rated the application significantly higher ($M = 2.08$) than the *grouping* cohort ($M = 0.96$).

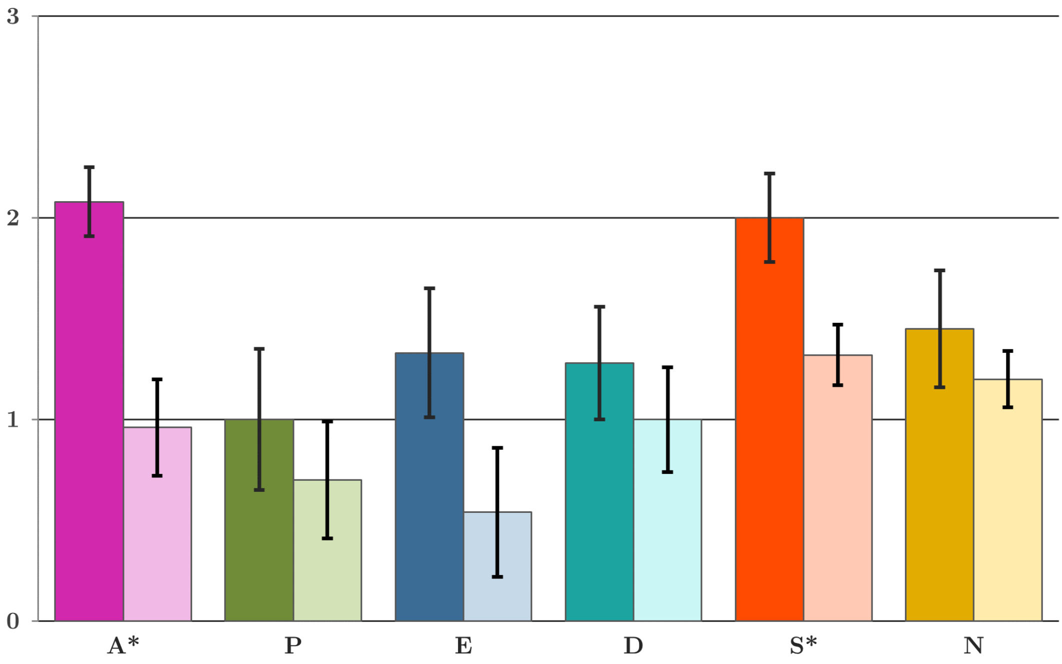


Figure 7.7 UEQ Metrics

A = Attractiveness, P = Perspicuity, E = Efficiency, D = Dependability, S = Stimulation, N = Novelty. UEQ scale range is [-3, 3] but is truncated due to absence of negative values. For A and S, significant difference was found between the two cohorts

For stimulation, the *sequential* cohort rated the application significantly higher ($M = 2.00$) than the grouping cohort ($M = 1.32$). These results are displayed in figure 7.7.

7.7.2 SSQ

The SSQ responses did not highlight any significantly elevated (moderate or severe on the SSQ) discomfort or any type of nausea for all participants bar one. This one participant noted a minor increase in discomfort, which they attributed to pins and needles in the hand holding the controller. This participant noted pre-existing issues with fine motor control of the thumb. For the purposes of statistical analysis, the SSQ responses were transformed with the following values: None = 0, slight = 1, Moderate = 2 and Severe = 3. The SSQ statistics are noted in Table 5.

Table 5 SSQ Metrics

SSQ Question	*M*	*M*	σ
General discomfort	0.21	0	0.51
Fatigue	0.13	0	0.34
Boredom	0.08	0	0.28
Drowsiness	0.04	0	0.20
Headache	0	0	0
Eyestrain	0.38	0	0.58
Difficulty focusing	0.08	0	0.28
Salivation increase	0	0	0
Salivation decrease	0	0	0
Sweating	0.04	0	0.20
Nausea	0.13	0	0.34
Difficulty concentrating	0.04	0	0.20
Mental depression	0	0	0
"Fullness of the head"	0.08	0	0.28
Blurred vision	0.21	0	0.41
Dizziness eyes open	0	0	0
Dizziness eyes closed	0	0	0
Vertigo	0.04	0	0.20
Visual flashbacks*	0.08	0	0.28
Faintness	0	0	0
Aware of breathing	0	0	0
Stomach awareness	0.04	0	0.20
Loss of appetite	0	0	0
Increased appetite	0	0	0
Desire to move bowels	0	0	0
Confusion	0.08	0	0.08
Burping	0	0	0
Vomiting	0	0	0
Other	0.08	0	0.41

7.8 Discussion

In this study, the aim was to see if interesting mind mapping strategies would emerge when mediated through VR. Promising outcomes were identified and their implications in general are discussed next.

7.8.1 Identification

Through the analysis of the task, the emergence of two previously unreported distinct strategies for organising the mind map were identified: '*grouping*' and '*sequential*'. This answers the first part of the research question, 'what behaviours or strategies emerge when participants construct a mind map through a VR mediated application'. These strategies showed clear visual differences in how the task was executed by participants. The *grouping* cohort created groups of related tiles first and re-organised these groups before creating their first links. The cohort worked linearly, extracting tile pairs from the carousel, and then defining the relationships immediately. Quantitatively, significant differences in first link event (*Sequential* ↑), first group creation event (*Grouping* ↑) and translation distances (*Grouping* ↑) were identified. Surprisingly, this did not increase the TCT (NS), the bounding volume (NS) or even errors (NS) for the *grouping* cohort. Qualitatively, the mind maps created by both cohorts were complete, of similar quality and utilised the full spectrum of available interactions. Significant difference in UEQ ratings for the attractiveness and stimulation metrics were also found (*Sequential* ↑).

7.8.2 Explanation

This chapter proposes that the emergence of the two distinctly different styles of engaging with mind maps is a result of differing use of epistemic versus pragmatic actions [126]. The *grouping* cohort performs *grouping* of tiles as an epistemic action. The *grouping* cohort sampled and built parts of the mind map, with frequent revisions and rebuilds, to explore how things fit better. In contrast, the *sequential* cohort used a cumulatively locked down approach. Kirsh et al. [126] originally identified that the main goal of epistemic actions is towards optimising input. In this case, task completion times did not differ significantly. Thus, it is proposed that the observed epistemic actions focused on supporting pedagogical synthesis of the mind map, i.e., supporting the primary goal of recalling the topic's content while building the mind map.

The variance between the average scores for two UEQ metrics (attractiveness and stimulation) between the two cohorts is an interesting observation. The *grouping* cohort scored the attractiveness and stimulation positively but lower than the *sequential* cohort. There is no obvious correlation to any of the other relevant metrics. The only indication comes from the free form feedback collected in the previous VERITAS usability study [238]. In querying the results from that study, user comments indicate a significant number would have liked to have been able to move groups of tiles at once. While the significance of these comments was not apparent in this previous study, the emergence of the two strategies in this current study provides context for these comments. It suggests that not allowing or enabling users to construct the mind map in a way that is most efficient for them leads to a significantly reduced user experience. These scores highlight the need to understand individual strategies for task execution in order to provide all the required affordances. Otherwise, the users adapt as best as possible, but the overall attractiveness of the application is lowered.

7.8.3 Generalisation

An important question is if such strategies emerge in other mediums? The initial background literature review did not find any explicit reference to identification of the distinct strategies in previous mind mapping research. However, this is possibly explained by most research being focused on usability of technology mediated mind mapping, rather than user behaviour and strategy in the construction of a mind map. An interesting area for future work would be to see if these strategies emerge in other mind mapping activities. Using a whiteboard with sticky notes would be analogous to the VR based activity described herein but would remove technology as a confounding factor. However, there is some indirect evidence from previous work. The difference in the two strategies, as suggested in previous CSCW literature [120] might create conflict when individuals from both cohorts work together in a collaborative mind mapping activity. The conflict resolution would require conversation related to spatial positioning of the mind map elements. Evidence of such conversation is reported by Jamil et al. [113]. Future work can definitively confirm the hypothesis that the strategies are inherent to individuals and independent of the medium.

7.8.4 Effectiveness

A significant pedagogical concern is learning effectiveness of approaches and tools. This study did not attempt to validate the effectiveness of mind mapping in VR. However, the work does rely on the accepted stance that mind mapping is an effective and widely used tool for learning. Since digital mind mapping tools already exist, the focus was on investigating behaviour instead of measuring effectiveness. The observations about the completeness of the mind maps do not raise any concerns about effectiveness. The question of formal evaluation of effectiveness is beyond the scope of this work.

7.9 Design Implications

To answer the second part of the research question, 'if unique behaviours or strategies emerge, what are their implications when considering collaborative mind mapping in VR', there is a need to consider previous CSCW research, educational perspectives, and application design.

7.9.1 Paragogy and Collaboration

The current scope of VERITAS, as a single-user mind mapping application, was essential to allow individual strategies to emerge. However, mind mapping is commonly carried out as a collaborative activity among peers. Peer-based collaborative learning or paragogy is commonly associated with inquiry-based learning and thus mind maps. Designers of collaborative mind mapping applications need to carefully consider the observations in their design. The naïve approach of offering a shared environment with different viewpoints is no longer a viable option. While the awareness of the actions of the collaborator is required, a whole new design approach is needed to display the mind map to the users.

The two mind mapping strategies, (*grouping* and *sequential*) that were identified, reveal challenges. When VERITAS is implemented in a collaborative environment, the two strategies may work well together, with users naturally mediating control to allow for their distinct strategy to continue unhindered. However, it is equally possible a user employing the *grouping* strategy may face disruption in reflection due to a competing user applying the *sequential* strategy or vice-versa. Unlike digital tabletops or paper-pen exercises that consist of a shared space and single perspective, VR headsets can operate independently of each other while supporting 'one-world, multiple perspectives', but the designer needs to look beyond merely supporting separate personal and shared workspaces.

The variety of mind maps built by the participants provide an insight into the information organisation process. While the space mediates the organisation of information, the correspondence of spatial coordinates to individual tiles is loose. This can be leveraged by a design wherein the tile positions in each user's view are loosely coupled to their positions in another user's views (i.e., if a user moves a tile to a new location, this change doesn't need to be reflected exactly in another user's view or the movement is replicated on a 'diminished' proxy). Interesting design choices need to be made when the collaborative discussion focuses on such a tile or when the relative spatial position of the tile becomes relevant to the structure of the mind map. An ideal implementation would allow both strategies to flourish on their own without hindering the reflective paragogy it is meant to foster. One possible outcome can be visually dissimilar but pedagogically similar mind maps. The implementation would also account for the hardware-imposed constraints of VR headsets that restrict the natural communication through face-to-face interactions and make contention issues harder to manage. The designer can leveraging existing work to virtualise face to face interactions through avatars [196] to facilitate non-verbal communication and introduce elements that increase situational awareness [21].

In addition to these finding being useful for designers of collaborative VR mind mapping applications, they are also useful for educators. Now that these behaviours are known and identified, educators can ensure any application they procure or utilise encompasses and facilitates these behaviours. Interactions that occur naturally ensures active learners do not become passive learners through frustration and disengagement. Learning activities can also be tailored to ensure such behaviours are catered for.

7.9.2 Application Design

The lower UEQ scores between the *sequential* and *grouping* cohorts for the attractiveness and stimulation metrics underlines the importance of designing an application that centres on the users and their needs (User Centred Design). Forcing or not allowing the users to behave in a manner most efficient or natural for them (such as allowing the moving of all grouped objects simultaneously in respect of the *grouping* cohort) can lead to a lower overall user experience. A particular recommendation is that VERITAS be updated to allow users to move groups of tiles together.

7.10 Limitations

In designing the experiment and choosing an appropriate VR mind mapping application, no attempt was made at this stage to account for neuro-diverse participants, students with learning disabilities or vulnerable populations. The study did not screen for or collect demographic data for these aspects. The obvious next step for this study is to build and test a collaborative VR mind mapping application, but in doing so designers should consider these aspects in line with previous work looking at ADHD (Attention Deficit Hyperactivity Disorder) [186] and VR for students with learning disabilities [253]. Designers of VR educational applications should also be aware of health and safety concerns and best practices, especially if intended to be used within the vulnerable populations listed above. As posited in a study investigating the assessment of cognitive function through a VR tool [131], VR may impact on the assessment and diagnosis of neurocognitive disorders. As VERITAS is primarily a cognitive exercise there may be similar considerations, however, this study approached the issue in the same manner and leave this as an area for future work by experienced neurological researchers.

It must be noted that no allusions are made to proving learning in VR mediated mind mapping and this is not the intent of this study. Instead, we rely on previous literature for education in VR and the effectiveness of mind mapping as an education tool to support this. Confirmation of effective learning in VR mediated mind mapping is left for future work.

7.11 Conclusion

This study aimed to explore how VR can facilitate the emergence of individual mind mapping strategies, thereby addressing RQ1, RQ1.1, RQ1.2, and RQ1.3. Using the VR mind mapping application, VERITAS, the study identified two distinct strategies, 'grouping' and 'sequential,' employed by participants in creating mind maps. This discovery directly contributes to answering RQ1.3, which focuses on understanding how users' cognitive behaviours manifest in a VR mind mapping application.

The identification of these strategies is significant in understanding the potential of low-cost VR devices (RQ1) to support engaging activities that target higher-order cognitive processes. The usability and effectiveness of the interaction workflow in VERITAS, as demonstrated by the participants' ability to effectively employ these strategies, provide insights into how VR can create engaging and interactive educational experiences (RQ1.1). The emergence of these distinct mind mapping strategies also sheds light on the potential of VR for domain agnostic learning (RQ1.2), showing how VR can facilitate cognitive processes essential for learning across various domains.

Moreover, the study's findings have implications for the design of VR applications, particularly for educational purposes. The need for applications to accommodate various user strategies to enhance the learning experience is evident. This includes considerations for collaborative environments in VR, where diverse strategies can coexist and complement each other. The study thus extends our understanding of how VR can be tailored to support not just specific learning objectives but also diverse cognitive approaches and styles.

This this study demonstrates the effectiveness of VR in supporting varied and individualised learning strategies through mind mapping, offering valuable insights for future research and application development in VR-based education. The unique affordances of VR in fostering individualized learning strategies and cognitive behaviours highlight its potential as a transformative tool in educational settings, addressing the complex requirements of RQ1, RQ1.1, RQ1.2, and RQ1.3.

Chapter 8

Discussion

8.1 Overview

This chapter provides a synthesised overview of the research findings, particularly focusing on the insights gained from the research questions outlined in Chapter 1. This discussion not only summarises the key outcomes but also reflects on their significance in the broader context of VR in education. This chapter aims to bridge the empirical data with theoretical implications, offering an understanding of how VR can transform educational paradigms. This chapter also provides a critical analysis of the findings in relation to the literature review presented in Chapter 3. It aims to juxtapose the research outcomes with the established theories and empirical studies in the realm of VR and education.

This thesis has methodically explored various dimensions of VR in educational contexts, presenting a synthesis of findings from Chapters 4 to 7. The evolution of VR from a novel concept to a mainstream educational tool has been analysed, highlighting both the potential and the practical challenges in its implementation. These insights offer a dual narrative: the transformative promise of VR in education and the realities of its integration.

Chapter 4's exploration into educators' perceptions and the adaptability of low-cost VR devices (Chapters 5 and 6) underscores the democratisation of VR technology. This accessibility is pivotal for interactive and immersive learning experiences, especially in budget-constrained settings. Educators have identified a range of applicable domains, expressing excitement yet caution about VR's educational opportunities. These findings resonate with the constructivist pedagogical theories, suggesting VR's aptitude in facilitating environments conducive to independent exploration and conceptual understanding.

The observations in Chapter 7 about user behaviours within a VR mind mapping application reveal significant insights. Distinct strategies like 'grouping' and 'sequential' mapping in VR indicate the emergence of varied cognitive behaviours in virtual environments. These findings are crucial for VR application designers and educators, emphasizing the need for applications that cater to these identified behaviours to enhance active learning.

Reflecting on these comprehensive findings, this thesis identifies several future directions for VR in education. First, there is a need for more intuitive and pedagogically sound VR applications. The rapid evolution of VR technology necessitates a continual adaptation of approaches for its integration into educational environments. Second, the potential of VR for diverse pedagogical applications highlights a gap between VR's potential and its practical implementation. Future research should focus on developing user-friendly VR content creation tools, simplifying the process of VR content development, and enhancing its adoption in educational settings.

Lastly, the integration of VR in educational settings aligns with the transformative role of Technology-Enhanced Learning (TEL). As VR technology continues to evolve, so must our strategies for its effective integration. This will require a focus on developing accessible, intuitive, and pedagogically sound VR applications, bridging the gap between technological potential and educational reality.

This thesis not only illuminates the opportunities and challenges of integrating VR in educational settings but also charts a path forward for future research and application development. The journey from novelty to a mainstream educational tool reflects the dynamic nature of VR technology, urging a shift in focus towards developing accessible and effective VR applications that align with current and future educational needs.

8.2 Main Themes

The previous chapters have individually explored educators' attitudes to VR, students' engagement with educational VR in comparison to existing desktop implementations, the design and implementation of an interactive thought-based

VR application on low-cost VR and finally the behaviours of users within a mind mapping VR application with a view to designing for collaborative educational spaces. Consideration is also made of the adaptions required to undertake this research during a global pandemic. Finally, future work is discussed, paying particular attention to collaborative VR usage and the tools needed for educators to best leverage VR within their practice. Essentially, this thesis identified four key conclusions: -

- VR may no longer be considered novel by some users. This negates the widely held assumption within education that VR itself is enough to lead to engaging session with high learner interactivity.
- Complex interactions supporting topic agnostic activities (such as mind mapping) are possible on low-cost hardware given adequate thought to control schemes and state models.
- Educators identify a wide range of applicable domains and are excited but cautious about the learning opportunities presented by VR.
- Creating problem-based educational scenarios within VR is currently challenging with no off the shelf solution currently available for domain agnostic activities.

This chapter provides detail on each of the above elements in the following sections.

8.3 Research Questions

RQ1: *Can low-cost VR devices support engaging activities that target higher order cognitive processes within a multi-user, collaborative educational setting?*

Addressing RQ1, we explored the viability of low-cost VR devices in fostering engaging and collaborative educational settings. The findings indicate that while VR's novelty factor has diminished, its educational potential remains. Low-cost VR devices, contrary to initial scepticism, can indeed support complex cognitive activities. This challenges the traditional assumption of high costs being a barrier to innovative VR applications in education. In addition, the background literature

indicated a need to firstly consider what is meant by the term engaging, as its definition in the literature was found to be inconsistent. There is also a general assumption that VR is automatically more engaging than desktop comparators but there is scarce evidence to support this. Thus, in Chapter 5 and through LogiBot, a study was conducted to answer this open question which determined that VR no longer appears to be more engaging than desktop application. The thesis further expands on the possible reasons for this in section 7.2.1. Additionally, through Chapter 5 and VERITAS as well as LogiBot, the thesis seeks to answer the low-cost part of RQ1. Chapter 6 concluded that by carefully selecting and utilising existing interaction methods that complex cognitive tasks can be completed on low-cost VR devices. This is expanded upon in section 7.2.2. We also use Chapter 6 to inform upon the collaborative element. While Chapter 6 was a first step in seeking to answer this part of RQ1, unfortunately the thesis is unable to adequately answer this due to a lack of experimentation. This is primarily due to a lack of time due to adaption required throughout the course of the pandemic or that maybe the research question was too ambitious in the first instance.
The implications of these findings are significant. They suggest that VR technology, once seen as a high-end luxury, is now accessible for wider educational use. This democratisation of VR technology opens new avenues for interactive and immersive learning experiences, even in settings constrained by budgetary limits.

The thesis utilises sub-research questions to further expand on answering RQ1.

- RQ1.1 *What specific and existing interaction paradigms and methods can be utilised to create engaging and interactive educational VR experiences?*

  Chapter 5 answers this question though the description of the system implementation and interaction design choices made, validated by a UES rating the application highly usable. It summarises that existing interaction methods, if carefully chosen and applied, can create engaging and interactive VR experiences within an education context. It essentially concludes that while new interaction methods may improve educational

VR, there is already enough research and design create engaging and interactive VR experiences within an education context.

- RQ1.2 *Can VR be used for domain agnostic learning.?*

  This question is effectively answered within the existing literature and supported by Chapter 4. Chapter 4 contributes to answering this question through surveys and interviews of educators. This study found that educators have wide ranging use cases that they would wish to use VR for across diverse pedagogical paradigm. The wish to use VR for thought exercises was an interesting discovery and informed subsequent research in this thesis. This is also explored in more depth in section 7.2.3.

- RQ1.3 *How do users' cognitive behaviours manifest when building mind maps within a VR mind mapping application??*

This is addressed through an exploratory study using the VR tool VERITAS. The study identifies two distinct mind mapping strategies, *'grouping'* and '*sequential*', with the former involving grouping related tiles before linking, and the latter linking pairs of tiles sequentially. Quantitative analyses, such as ANOVA, validate these strategies and explore differences in task metrics. Spatial volume usage and interaction analysis reveal significant differences in tile movement between the cohorts. The study also suggests that these distinct styles emerge from different uses of epistemic versus pragmatic actions. UEQ scores indicate differences in attractiveness and stimulation between the cohorts, highlighting the importance of application design tailored to user needs. These findings are valuable for VR application designers and educators, emphasising applications that cater to identified behaviours to enhance active learning.

RQ2: *What are the key factors in creating, organising, and delivering VR content in education?*

In chapter 4, surveys and interviews with educators revealed various desired uses for VR in education, including simulations, games, brainstorming, mind mapping, concept-mapping, and collaborative elements. However, respondents struggled to envision populating VR worlds with relevant educational resources, indicating a lack of familiarity with systems and technical expertise. To address these barriers, a PowerPoint-like, VR-focused application with an intuitive interface could simplify the creation process and facilitate immersive learning experiences. While the emergence of VRChat has already alleviated many of these obstacles by democratising access to educational information and enabling immersive learning environments without specialised skills, a tailored application could further enhance VR adoption in classrooms.

Concerning RQ2, our research revealed the factors needed for VR integration in educational contexts. Educators highlighted the potential of VR for diverse pedagogical applications, yet also expressed challenges in content creation and technical expertise. This underlines a gap between the potential of VR and its practical implementation in educational settings.

The findings and how they answer the research questions are discussed in more detail below:

- RQ2.1 *What do educators want to use VR for in their pedagogy?*

  Through a survey and interview of educators in Chapter 4, it was identified that a wide range of use that educators would want to use VR for. These included simulations, games, brainstorming, mind mapping, and concept-mapping. Collaborative elements were also apparent. The result of thought exercises, mind mapping especially, informed the subsequent studies.

- RQ2.2 *What barriers exist to educators wanting to implement VR within their learning environments?*

  While answered somewhat generically in the existing literature, Chapter 4 explored this in greater detail. The key finding was that respondents struggled to describe or even conceive how they would populate VR worlds with relevant educational resources. This points to an unfamiliarity with systems due to the fact that there is no easy way to populate VR worlds by educators, especially those with little or no technical expertise. Solutions to this are explored in 7.4.5.

- RQ2.3 *What tools or processes need to exist to enable effective use of VR by educators?*

  Having identified the barriers (RQ2.2), section 7.4.5 is used to discuss the answer to this question. To summarise here, educators have traditionally faced technical and skill-based barriers in utilising VR in classrooms. Developing a PowerPoint-like VR focused application with an intuitive, user-friendly interface could help overcome these obstacles, enabling teachers to create immersive and interactive learning experiences. By simplifying the creation process and handling technical aspects like rendering and stereoscopic display, this application would allow educators to focus on curriculum-relevant content. Moreover, easy access and distribution via learning management systems or email would further facilitate VR adoption in classrooms. However, upon further reflection, the emergence of VRChat since starting the research has already resolved many of these barriers. This platform democratises access to educational information, allows educators to create immersive learning environments without specialised skills, and incorporates visual aids like 3D models and simulations for better understanding of complex concepts.

These findings are a call to action for developing more user-friendly VR content creation tools. Simplifying the process of VR content development could significantly enhance its adoption in educational settings, allowing educators to focus more on pedagogy and less on technical hurdles.

8.4 Implications

The research undertaken presents a dual narrative: the promise of VR in education and the practical challenges in its implementation. While VR's potential to revolutionise educational experiences is undeniable, there is a clear need for more intuitive tools and platforms that align with educators' expertise and curriculum needs. As VR technology continues to evolve, so must our approaches to its integration in educational environments.

This thesis has illuminated both the opportunities and challenges of integrating VR in educational settings. The journey from novelty to a mainstream educational tool reflects the rapid evolution of VR technology. As the education sector moves forward, the focus should shift towards developing accessible, intuitive, and pedagogically sound VR applications, bridging the gap between technological potential and educational reality.

Due to the various adaptions made to this piece of research to mitigate the effects of the Covid pandemic, especially with regards restrictions of conducting studies in person with VR devices, it has been extremely challenging to answer all of the above research questions adequately. This section is thus used to provide context to the research undertaken, how the existing literature supports this and the additional questions and uncertainties that arose.

8.4.1 VR Novelty and Engagement

The exploration of VR interactions and student engagement in Chapter 5 reveals both similarities and contrasts with earlier literature. While the existing literature focuses on general engagement theories, Chapter 5 provides examples of how these theories are applied in VR settings. This practical application contributes to the field by moving from theoretical discussions to real-world implications. Finally, the emphasis on user engagement and interface design in VR learning environments aligns with the insights from O'Brien et al. [176] in their study on user engagement with the refined user engagement scale (UES) and its application in educational contexts. The exploration of VR interactions in Chapter 5 is deeply rooted in the theoretical frameworks and studies presented in Chapter 3. The emphasis on immersive and interactive learning experiences in VR draws upon the principles of experiential learning as discussed by Kolb [130]. This is particularly relevant in understanding how VR can facilitate learning through experience and reflection. Moreover, the findings of Merchant et al. [162] in their meta-analysis of VR-based instruction's effectiveness provide empirical backing to the strategies discussed in this section. Their work underscores the importance of interactive and engaging content for effective learning outcomes, which aligns with the approaches to VR interaction design discussed here.

While VR was once regarded as an original and forward-thinking concept, the evidence throughout this thesis suggests this perception has started to change. The VR industry has experienced rapid growth over the past few years with large companies such as Meta, Valve and Sony constantly driving innovation on the hardware front. This has also led to an increased availability of VR devices, applications, and content. Because the technology has become less expensive, more widely available, and simpler to operate, virtual reality can now be experienced by a much larger population. As a consequence of this, VR is no longer regarded as a novel (as evidenced in Chapter 5) or distinctive idea; rather, it has evolved into a widespread technology that has permeated a variety of fields, such as video gaming, education, healthcare, and the entertainment industry.

The increased availability of VR hardware is one of the primary reasons why virtual reality is no longer regarded as something ground-breaking. Historically VR technology could only be found in specialised research labs and training simulations used by the military. Because the equipment was so cumbersome and expensive, it was difficult for the average person to experience VR beyond technology demonstrations at universities for example. However, developments in technology, even during the brief time period covered by this thesis, have made it possible for consumers to purchase VR devices that are both affordable and easily accessible. Some examples of these types of devices include the Oculus Quest, HTC Vive, and PlayStation VR. The proliferation of these devices has made it possible for consumers to experience VR in the comfort of their own homes, which has led to a wider acceptance and comprehension of the technology.

The rapid growth and availability of VR content is another factor as to why the novelty factor of VR is waning. The industry has seen a surge in the development of VR content across multiple domains, such as gaming, education and training, and immersive entertainment. The availability of high-quality VR content has made it possible for consumers to experience VR in a variety of ways, beyond the nascent gaming uses common amongst most new technology. As illustrated in the literature, VR can be used to provide virtual tours of historical sites, simulations of surgical procedures, and interactive educational experiences. This growth of VR content, both from commercial developers and in the research field, has broadened the potential uses and applications of VR, making it an integral part of many industries, including education.

The increased affordability and accessibility of VR technology has also contributed to its mainstream adoption. In the past, VR was considered a luxury item, with devices costing thousands of dollars. However, with the development of new VR devices, the cost of VR technology has come down significantly, making it possible for a wider audience to experience VR. The affordability of VR devices has led to an increase in the number of consumers using VR technology, which has further broadened its acceptance and understanding.

Another factor contributing to the mainstream adoption of VR is the user-friendly nature of the technology. In the early days of VR, the devices were difficult to use and required specialised training to operate. However, advancements in VR technology have made it possible for consumers to experience VR with ease. VR devices now come with intuitive controls, making it possible for users to quickly understand and use the technology. The user-friendly nature of VR has made it possible for a wider audience to experience the technology, contributing to its widespread adoption.

Finally, VR has become a mainstream technology due to its widespread integration into various industries. VR technology has been used in gaming for several years, providing players with an immersive and interactive gaming experience. However, VR has also been integrated into other industries, including education, healthcare, and entertainment. In education, VR is used to provide students with interactive and immersive learning experiences, while in healthcare, VR is used to provide patients with virtual therapy sessions. In the entertainment industry, VR is used to provide audiences with immersive experiences, such as virtual concerts and interactive movies. The integration of VR into these industries has contributed to its mainstream acceptance and understanding.

Thus, this thesis proposes that VR is no longer considered a novel technology due to the increased availability of VR devices, the growth of VR content, its affordability and accessibility, its user-friendly nature, and its integration into various industries. VR has become a mainstream technology that has infiltrated various industries, providing consumers with new and innovative experiences.

8.4.2 Low-Cost VR

Low-cost VR devices are an interesting topic, and one initially attempted to be addressed in both Chapter 5 and Chapter6. However, since the initiation of this thesis, the hardware field has changed remarkably. Whilst this section does touch on the cost issue in the previous section, it is worth exploring here in more detail.

Initially, the low-cost domain was represented by the Samsung Gear VR and Oculus Go, both 3DoF devices. Over the period of just three years, the market has seen the iteration of two Oculus Quest devices (Quest 1 and Quest 2, now Meta Quest 2) and other entries into the market including devices such as the Pico Neo 3 and Pico 4. These devices are all Android based, untethered, and include full 6DoF tracking of the headset and dual controllers. The use of depth cameras on headsets also allows controller less hand tracking. This convergence on similar hardware and capabilities has made it somewhat easier to consider and assess the types of pedagogical activities that can be conducted within current VR. The next set of capabilities that appear poised to enter the VR hardware market is eye tracking, opening up new possibilities of interaction with VR. This rapid development of VR hardware has both been unanticipated and has all but eliminated low-cost 3DoF devices from the market, with Oculus sunsetting the Go device on 18th December 2020, just 30 months after its introduction. Furthermore, a once perceived growth area, mobile phone VR, has all but disappeared from the market. However, the approach to employing interaction schemes for complex processes on low-cost devices identified in this thesis still applies to the current VR landscape. Assessing the capabilities of the lowest VR denominator and creating suitable schemes and state models allows education applications and activities to be available on the widest gamut of devices. This is particularly important at a time when educational budgets are stretched and challenged, leading to widening participation.

8.4.3 Educators Perceptions of VR

Chapter 4 focused on the educator's perspective when considering VR use within education. The majority of educators see VR as a tool with significant potential for enhancing the educational experience for their students. They believe that VR can provide an immersive and interactive learning environment that allows students to experience real-life scenarios and situations in a safe and controlled environment. This can help students understand complex concepts in a more intuitive and engaging manner, leading to increased motivation and engagement. In the study into the perceptions of educators towards VR, the use of the technology for thought exercises (concept / mind maps etc) provided an interesting direction for further investigation, one not anticipated.

In addition to the studies against VERITAS (Chapters 6 and 7) that dealt with the thought exercise aspect, a study in collaboration with Masters students within Lancaster University studying the SCC.402 'Innovations in Interactive Computing' module was also conducted. The study titled 'Step into My Mind Palace: Investigation of a Collaborative Paragogy Tool in VR' [236] investigates the use of VR as a collaborative learning tool for enhancing memory recall and critical thinking abilities. Participants in the study utilised a VR application called "Mind Palace" to create and explore memory palaces, which are imagined spatial locations used to store and recall knowledge. Participants created and shared their memory palaces in groups, allowing for collaborative learning and knowledge sharing. The study revealed that the usage of VR as a collaborative learning tool increased memory recall and critical thinking skills, and the participants considered the experience interesting and pleasurable. This study is pertinent to the use VR for thought-based exercises in education because it highlights the potential of VR as a tool for collaborative learning and enhancing cognitive skills. In addition, the collaborative feature of the VR tool can enable peer learning and the exchange of knowledge, thereby enhancing the learning experience.

In concert with responses from study participants, the existing literature shows that VR can be used in science classes to bring students to the surface of a distant planet, or in history classes to transport students back in time to experience historic events first-hand. Additionally, VR can also be used in fields like medicine, where students can practice procedures in a virtual operating room, or in architecture, where students can design and experience virtual buildings.

Educators also see VR as a valuable tool for providing students with hands-on, experiential learning opportunities. Unlike traditional methods of teaching, where students are confined to a classroom, VR provides a platform for students to explore and discover on their own, leading to a deeper understanding of the subjects being taught. This research underscores a critical aspect of VR in computing education, as explored in Chapter 4. Active learning practices such as project-based and peer learning are found to be effectively supported by VR environments. This aligns with previous research suggesting traditional lecture methods are less effective in computer science education, thereby validating VR's role in fostering a more interactive and engaging learning experience.

Thus, through this research and alongside existing research, it was identified that educators have a wide range of ideas for how VR can be used in their classrooms. Some of the most common applications include:

- Enhancing visual and auditory learning: VR can be used to create interactive, multimedia experiences that combine audio, visual, and haptic feedback. This can be especially useful for subjects like drama, history, science, and geography, where students can experience different cultures and historical events first-hand.
- Improving problem-solving skills: VR can be used to provide students with hands-on, interactive challenges that require them to apply critical thinking and problem-solving skills. This can be beneficial for subjects like mathematics, physics, and engineering, where students can experiment with virtual simulations to learn about different concepts and theories.
- Supporting collaboration and teamwork: VR can provide students with a platform for collaboration and teamwork, allowing them to work together in virtual environments to achieve common goals. This can be beneficial for subjects like business and marketing, where students can work together on virtual projects and simulations.
- Improving emotional intelligence: VR can be used to create simulations that allow students to experience real-life scenarios and emotions, such as empathy and compassion. This can be beneficial for subjects like psychology and social sciences, where students can learn about human behaviour and emotions in a controlled environment.

Reflecting on pedagogical theories, our findings resonate with the constructivist approach detailed in Chapter 3. The VR applications in education allow students to engage in self-directed learning within a constructivist framework, closely mirroring Piaget's [194] and Vygotsky's [265] theories on cognitive development and scaffolding. This suggests VR's aptitude in facilitating an environment conducive to independent exploration and conceptual understanding.

8.4.4 Barriers to Adoption

Chapter 4 also explored the barriers to adoption of VR within education. In concert with the existing literature and the surveys and interviews in Chapter 4, it was found that educators may be hesitant to implement virtual reality in their classrooms owing to a number of perceived challenges, including expense, technical competence, access to content repositories, restricted accessibility, lack of standards and rules, limited research, time, and support from leaders.

The discussion in Chapter 4 on the practical challenges of VR in education can be further illuminated by linking back to specific literature explored in Chapter 3. For instance, the challenge of integrating VR into existing educational frameworks relates to Kaufmann, Schmalstieg, and Wagner's [121] exploration which highlighted similar integration issues. The observed difficulties in user engagement with VR environments are in line with O'Brien et al.'s [176] research on user engagement scales in educational settings. Furthermore, Merchant et al. [162] provide a comprehensive meta-analysis on the effectiveness of VR-based instruction, which underscores the challenges identified in this section regarding the implementation and efficacy of VR in educational contexts. Lastly, the issue of creating intuitive and user-friendly VR experiences echoes concerns raised by Huang et al. [13] in their investigation into learners' attitudes towards VR learning environments. By connecting these challenges to the established literature, this section not only contextualises the practical difficulties but also contributes to a deeper understanding of the ongoing evolution of VR in educational settings. One of the most obvious major barriers to the adoption of VR in education is cost. Even budget VR technology can be expensive in terms of school funding, and many schools and educators may not have the budget to purchase VR headsets and other hardware for their students. The cost of VR hardware can be prohibitively high for some schools, particularly those located in low-income areas.

Another barrier to the adoption of VR technology in education is the lack of technical expertise on the part of educators. Some educators may not have the technical knowledge and expertise to effectively integrate VR technology into their lessons and curriculum. This can make it difficult for them to use VR technology to its full potential and deliver meaningful and engaging educational experiences for students.

A lack of high-quality, educational VR content can also be a barrier to adoption. Educators need access to VR content that is relevant and appropriate for their students, but this content may not always be readily available. This can limit the use of VR technology in the classroom and make it difficult for educators to deliver engaging and effective lessons.

Some educators may be resistant to adopting VR technology because they prefer traditional teaching methods and believe that VR will interfere with the educational experience. Educators may be concerned that VR technology will distract students and reduce their attention to the lesson. They may also be concerned that VR technology will replace traditional teaching methods and limit their ability to engage with students in a meaningful way. Some educators may be resistant to changing their teaching methods and adopting new technology, even if it has the potential to enhance the educational experience. Educators who are comfortable with traditional teaching methods may be reluctant to adopt VR technology and may not see the benefits of incorporating it into their lessons.

VR technology may also not engage all students in the same way, and some students may struggle to become immersed in the VR environment. Educators may find it difficult to deliver lessons that are relevant and engaging for all students, particularly those who are less technologically proficient or have diverse educational needs. In tandem with this, educators may have concerns about the potential health and safety risks associated with VR technology. For example, some students may experience motion sickness, eye strain, or headaches when using VR technology. Educators may be concerned about the potential for injury or other health problems associated with the use of VR technology, and this may limit its adoption in the classroom.

In summary, several barriers to the adoption of VR technology in education from an educator's viewpoint were identified, including cost, technical expertise, lack of content, interference with traditional teaching methods, student engagement, health and safety concerns, and resistance to change. However, despite these challenges, educators realise that VR has the potential to revolutionise education and enhance the learning experience for students. It is important for educators to understand the barriers to adoption and work to overcome them in order to realise the full potential of VR technology in the learning environment.

Our findings suggest a significant alignment with the transformative role of TEL, as discussed in Chapter 3. The integration of VR in educational settings echoes the meta-analysis insights on blended learning, highlighting VR's potential to enhance student engagement and collaborative behaviours. However, unlike the smooth adoption trajectory of TEL, VR faces unique challenges in terms of content creation and technical expertise, emphasising the need for more streamlined VR educational tools.

8.4.5 Creating VR Educational Experiences

Building upon the foundational theories and models presented in Chapter 3, the recommendations in this section offer practical applications and extensions of these concepts. For instance, the work of Kaufmann, Schmalstieg, and Wagner [121] underpins the proposed strategies for enhancing spatial understanding through VR. Their early exploration into VR's potential in education parallels the more recent developments and applications discussed in Chapter 3, illustrating the growth and refinement of VR as a tool for enhancing student engagement and interaction in educational contexts. Furthermore, the principles of active and experiential learning, as discussed in Kolb's [130] work are reflected in the recommended VR teaching methodologies. This section also takes into account the findings of Merchant et al. [162] in their meta-analysis on the effectiveness of VR-based instruction, which supports the proposed use of VR for diverse educational purposes.

While Chapter 4 outlined practical challenges to using VR within education, the true difficulty in developing an educationally challenging experiences lies in outlining appropriate problem-scenarios and identifying the appropriate supporting pedagogy to do this. This challenge is compounded by the fact that the VR environment is the new location for the activity. In this research, educators not conversant with VR appear unsure how to fully utilise VR environments, or they may be concerned with the content' that required for the learning activities. An attempt to address this issue is made in later sections (8.4.5 and .6.4).

VR interactions are considered especially in Chapter 6. Appropriate and intuitive interactions within VR are important because it engages students and makes the VR experience more meaningful and impactful. The VR content should be designed to allow students to interact with the virtual environment, either through hand-held controllers or through body movements. This will help to keep students engaged and enhance the overall educational experience. The VR content should also provide an engaging and immersive experience for students. This can be achieved through the use of high-quality graphics, audio, and visual effects. The VR content should be designed to transport students to a different world (and not necessarily representation of the 'real world') and allow them to experience and explore the virtual environment in a meaningful way.

Accessibility is an additional element to consider when creating VR educational content. The VR content should be designed to be accessible to all students, regardless of their ability levels or technological proficiency. This can be achieved through the use of clear and simple controls, as well as accessible and inclusive design practices. The VR content should also be easy for educators to use and integrate into their lessons and curriculum. The VR content should be designed to be user-friendly and intuitive, with clear instructions and simple controls. This will help to minimise the learning curve for educators and make it easier for them to incorporate VR technology into their teaching practices.

Thus, creating high-quality, educational VR activities and content requires careful consideration of several key factors, including relevance and appropriateness, interactivity, engaging and immersive experiences, accessibility and ease of use. By taking these factors into account, it is possible to create VR educational content that is impactful, meaningful, and accessible to all students.

8.5 Recommendations

8.5.1 General

In concert with the existing literature and drawing on the experience of designing and building the artifacts for the studies within this research, the general recommendations for creating VR educational experiences are as follows.

When building virtual reality experiences, the designer should keep in mind that the user is completely immersed in a digital environment and to create the experience such that it seems natural and intuitive. Experiences should create an atmosphere that the user perceives as authentic and plausible. Using high-quality images, realistic sound effects, and haptic feedback can achieve this goal. As VR can occasionally induce motion sickness, rapid movements should be limited, and the user should have a sense of control over their movement. VR environments environment should be simple to navigate and comprehend, with clear directions and indications. Designers should ensure that the user may leave the virtual reality experience if they feel uneasy or need a break. Consider accessibility for users with impairments and offer alternatives for users with varying requirements.

The recommendations provided here are informed by both the practical insights gained in Chapters 5 and 6 and the theoretical underpinnings discussed in literature review. This synthesis of theory and practice highlights the evolution of VR in education, offering a more holistic view than previous literature.

8.5.2 Observed Behaviours

Through the literature, several behaviours are common. Users do try to move objects at the same time; however, users will relinquish control of an object if the perceive another's actions is correct (termed collaborative interplay). There appears to be a pseudo democratic consensus approach to working on the same objects (i.e., a user may accidently make an object to large which triggers a group response to reduce the size of the object back to normal without any verbal or non-verbal prompting). Users will voluntarily co-locate to be near peers when working on the same part of the diagram. User behaviour in VR might vary based on application, environment, and individual user characteristics. All illustrated in chapter 7, there are distinct behaviours and strategies emerge between different users. Accounting for this difference is critical to designing and building effective collaborative applications.

When users enter a virtual world, they often investigate their surroundings by moving about and examining items. This behaviour is enabled by the freedom of movement inside the VR environment, which heightens the sensation of presence and immersion. The exploration behaviour might also rely on the application, with some applications, such as training simulations or games, encouraging users to engage with the environment. Depending on the VR application, users may also interact with the virtual world and objects in a variety of ways. To move things or interact with other virtual characters or avatars, users may utilise hand gestures, controllers, or other input devices. This action can generate a sense of agency and control over the virtual world, as well as heighten a sensation of presence.

The sensation of presence is one of the most prominent behaviours noticed in virtual reality. People frequently describe feeling fully present in the virtual world, which may be a transformational and potent experience. Many elements, including the quality of the VR system, the type of application, and the cognitive and perceptual capacities of the particular user, might impact the experience of presence. In addition to these activities, VR may elicit a variety of emotional responses from users. Depending on the content and context of the VR experience, users may experience emotions such as awe, exhilaration, or even terror. More study in this area is expected to unearth further insights and uses for VR.

8.5.3 Gestalt Mapping

An interesting observation from the study in Chapter 7 was the confirmation of gestalt mapping being evident in the creation of mind maps for some users. Before exploring why gestalt mapping is relevant to designing for collaboration and understanding user behaviour, it is first useful to explore the term in more detail.

Gestalt mapping is a method for visually organising and representing information, such as ideas and concepts. It is founded on the concepts of gestalt psychology, which suggest that the human mind organises information into patterns and configurations that are more significant than the sum of their parts. Typically, gestalt mapping includes the creation of a visual map or diagram that depicts the links between various ideas or concepts. The map can be built with a number of tools and methods, including sketching, writing, and the use of premade symbols. The map may have several features, such as labels, photos, and lines connecting various concepts. Complex information, such as research data, project plans, and business models, may be organised and comprehended via gestalt mapping. It may also be utilised for brainstorming, problem-solving, and making decisions. In a collaborative workspace, individuals may have different ideas and perspectives on a problem. Gestalt mapping can be used to map out these ideas and identify common themes, patterns, or connections. By visually organising and presenting ideas, teams can better understand the different perspectives and identify potential solutions. In workspaces that involve data analysis, gestalt mapping can be used to map out complex data sets. By visually representing the data, teams can identify patterns and relationships that may not be immediately apparent in raw data. This can lead to better insights and decision-making.

The following are examples of gestalt mapping techniques:

- Mind mapping: A process involving the creation of a visual map of interconnected thoughts or ideas.
- Concept mapping: A process involving the creation of a visual map of concepts and their interrelationships.
- Data Visualisation: Developing a visual map of the phases in a process or the flow of data.
- Storyboarding: A process that includes generating a visual map of a story's scenes or a project's phases.
- Organisational charting: A method of providing a visual representation of an organisation's structure and relationships.

Gestalt mapping may be a valuable technique for assisting individuals in comprehending complicated material and making connections between diverse concepts. It may also be utilised for brainstorming, problem-solving, and making decisions. Gestalt mapping emerges in most object/information/relationship collaborative work. Overall, gestalt mapping can be a powerful tool for facilitating collaboration and teamwork in interactive workspaces. By providing a visual representation of complex systems or problems, teams can work together more effectively and make better decisions.

To contextualise this against CSCW research, gestalt mapping can assist organisations in visualising and analysing complicated data, including massive datasets and intricate operations. By decomposing these complex systems into smaller, more manageable components, teams can gain a deeper understanding of how these systems function and identify areas for development or optimisation. Designing systems that allow for operations against gestalt mapping allow for the associated behaviours to appear unhindered, contributing to a system that meets the user's needs.

8.6 Limitations

The main factors that affected the way that the studies were designed, implemented, and assessed for this thesis were twofold. The first being the rapid advance of VR technology, especially in the sense of cost effective 6DoF devices such as the Oculus Quest coming to market during the course of this thesis. Secondly, the COVID pandemic, which prevented the running of studies with participants due to obvious health and safety concerns. The rapid advancement of VR is dealt with first.

In light of the rapid advance of VR technology especially low-cost headsets, VERITAS was rebuilt to take advantage of the 6DoF functionality of the Oculus Quest, such as including to dual controller movements for expanding the size of tiles, a redesigned push/pull and resizing metaphor, and reworking the tile orientation functions. There was an attempt to solve a common issue or object selection and interaction within 3D environments, namely the difficulty in selecting occluded objects. A nearest neighbour ray cast selection was implemented and coupled it with 'deck of cards' like selection wheel so the user could scroll through all possible tiles for selection that were otherwise occluded.

Additionally, collaborative elements were introduced, which took advantage of network elements such as Photon Unity Network (PUN). This implemented various elements discussed in the collaboration section above, such as a 'window into the world' (figure 8.1) where multiple users and VR devices could connect to the same environment and work on manipulating the tiles, but you could also have an Android device which focuses on the activity within the room. Within the Android device, you move your camera around to see different perspectives and what the users were working on at the time. This could have been used by teachers as a classroom management tool, which was a concern that was raised in Chapter 4. Furthermore, extra feedback elements were introduced so it was clear to all users what current tiles are being worked on by other users. System state

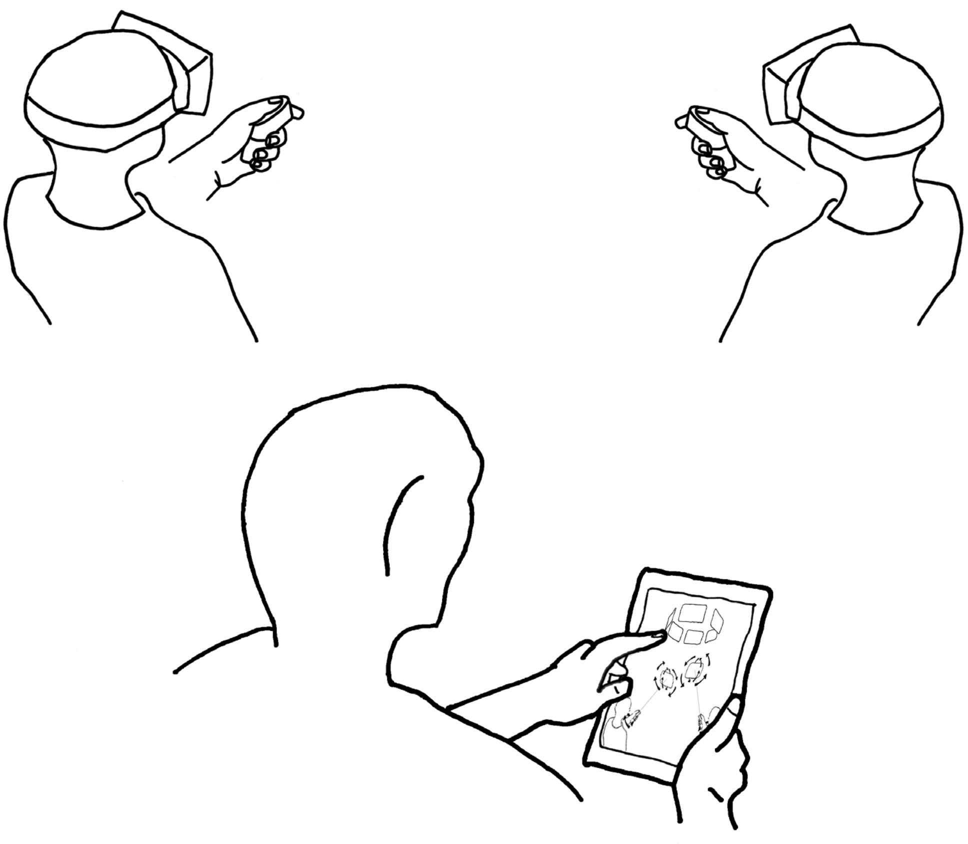


Figure 8.1 Concept for a 'window into the world' implementation

feedback included an avatar for each user, which was absent in the single user version of the system, so that other users could be aware of gaze direction for example. Additional object highlighting was also utilised such as extra colours to communicate which tiles were being manipulated by other users. If another user was working with a tile for example, that would have a unique colour to show that other users would not be able to interact with that.

This thesis would have ultimately liked to have completed these iterations of VERITAS and conducted an in the wild study for this. This study would have served two purposes. One, to assess the collaborative aspects of such a system and fully evaluate the design decisions and recommendations output from the single user studies conducted within this thesis. Secondly, to assess the effectiveness of learning in such a system. Being unable to assess learning is perhaps the biggest deficit within this thesis. This brings us on to the second factor, that due to the COVID pandemic, these versions of VERITAS were not able to be studied or experimented upon.

Due to apparent health and safety concerns, the advent of the pandemic immediately stopped all planned experiments using VR headsets and human volunteers. A considerable amount of work was devoted to identifying various study activities that might accommodate the research, including remote studies for collaborative VR-based investigations. Unfortunately, this proved to be a dead end due to the difficulty in locating a sufficient number of participants with access to the necessary hardware and the ability to load the software artefacts that had been developed onto the devices, as well as the fact that participants were facing their own challenges as a result of the pandemic. As a consequence, the research questions were reformulated to rely more heavily on these original studies, as described in chapter 4, for which the survey pool was extended, and more participants were interviewed. A second examination of the responses was then performed to derive deeper insight than had previously been made. Chapter 7 was intended to be a much smaller study that informed the collaborative version of VERITAS; however, given that there was an inability to conduct in-person studies, it was decided to reanalyse all the results in greater detail so that the design question of collaborative VR could be approached in a more 'design fiction' manner. These limitations feed directly into the subsequent section of this thesis, future work, which is unusually lengthy due to the factors described above.

8.7 Future work

Reflecting on the limitations and future work in light of the literature review, it is evident that while many challenges remain consistent, new areas of exploration have emerged. This section not only acknowledges ongoing issues but also charts new directions for research, demonstrating the thesis's contribution to the evolving landscape of VR in education.

8.7.1 Addressing Barriers to Adoption

As already identified, educators are frequently prevented from utilising VR in their classrooms due to a variety of technical or skill-based barriers. The elimination of these obstacles and the facilitation of the creation of virtual environments by teachers through the use of an application similar to PowerPoint could be the key to realising the potential of VR within education. Creating a VR environment has traditionally required a high level of technical skill as well as the use of specialised software. For educators who possibly do not have the necessary technical expertise or resources to create their own virtual environments, this can be a significant obstacle to overcome. An application that is comparable to PowerPoint would make the process easier to understand and complete by supplying an intuitive and user-friendly interface that is already well known to the vast majority of educators. An application that allowed them to simply drag and drop different elements, such as images, videos, and 3D models would be immediately familiar. The application would take care of the technical aspects, such as rendering and stereoscopic display, in the background, freeing teachers up to concentrate on the creation of content that is interesting and pertinent to the curriculum they are teaching.

An application comparable to PowerPoint would make it much simpler for teachers to show their students the virtual environments they have created for them. They would only need to upload their presentations to a learning management system or send them to the students in question via email for the students to be able to access them from any location. This would remove the technical barriers that prevent teachers from using virtual reality in their classrooms. This would make it simple and convenient for teachers to create immersive and interactive learning experiences that can improve students' engagement and comprehension of the material.

However, the above recommendation of a PowerPoint like application to resolve barriers to world building and content creation by educators within VR was reached early in this research. Upon reflection at the end of this thesis, it now looks a little naive. As is common when conducting research in popular fields of inquiry, multiple parties often arrive at similar conclusions or produce artifacts that solve the same problem. In this instance, the artifact that appears best placed to resolve these barriers appears to be VRChat [202]. VRChat has changed education within VR and eliminated multiple hurdles to teaching. In addition to democratising access to educational information, it has enabled immersive and interactive learning environments to be created by educators with simple and easily understood tools. It has removed the barriers such and needing to know how to 3D model and code. Now educators are able to create engaging and interactive learning environments themselves. Teachers can use 3D models, simulations, and other visual aids to help students better understand complex concepts. This kind of experiential learning once restricted to packaged experiences produced by educational content companies can now be created by educators themselves.

8.7.2 Refine the Pedagogy

While this thesis restricted itself to the pedagogical concept of active learning within the constructivist paradigm, there remains opportunity to refine the pedagogy surrounding the use of VR within education. This thesis already looks at paragogy through the lens of collaboration, however there are other elements that warrant further exploration. For example, authentic learning experience are a contemporary area of active research [94]. This is particularly relevant where authentic learning has become a buzzword in apprenticeship education, where students learning experiences should reflect and improve their workplace practice. VR is ideally placed to adhere to this new thinking where the VR environment can offer an authentic and relevant learning experience. Simulations and scenarios can be realistic and relatable to the real world, providing students with opportunities to apply their learning to real-world situations. Further research will increase the relevance and meaningfulness of these learning experiences.

Additionally, feedback for students, both formative and summative, and real-time, is a constant focus in high quality educational practices [188]. It would be worth exploring how VR educational systems could provide students with immediate feedback on their actions and decisions. VR can offer various types of feedback, such as visual and auditory cues, haptic feedback, and gamification elements. As feedback is essential for the learning process by helping students identify their strengths and weaknesses, adjust their thinking, and progress through the learning material there is opportunity here, along with AI, to leverage VR as a differentiator among other TEL systems.

8.7.3 Assessing Learning

Assessing learning within a virtual reality educational system, or indeed any TEL system, can be challenging, but there are several methods that can be used to evaluate students' understanding and progress. One approach is to use value added assessments, or pre and post, to measure the learning outcomes of students prior to and after they use the system. Pre-assessments can be used to gauge prior knowledge and identify areas where students need more support. Post-assessments can then be used to evaluate learning outcomes and determine the effectiveness of the system.

Another approach is to use self-reflection and feedback mechanisms. After using the system, students would reflect on their learning and receive feedback. This could include prompts for self-reflection or a feedback mechanism within the VR environment itself. Students could also be given the opportunity to provide feedback on the system, which can be used by both educators and tool designers to improve its effectiveness.

VR tools could also track and record a user's actions and interactions within the environment. This can provide valuable data on their behaviour and decision-making processes. For example, in a virtual reality simulation for medical training, the system could track a user's performance in completing a procedure or making a diagnosis.

Performance metrics can also be used to assess learning in such a system. Environments can be designed to include tasks or challenges that require specific skills or knowledge. Performance metrics, such as completion time or accuracy, can be used to evaluate student performance and determine areas where they may need additional support or practice.

Thus, future work that looks at assessing learning within a virtual reality educational system requires a combination of approaches that may include pre- and post-assessments, self-reflection, and feedback, tracking user behaviour, and performance metrics.

8.7.4 Longitudinal Studies

There can be no doubt that both within the existing literature and within this research itself that VR use in education has shown promise in enhancing learning outcomes, student engagement, and motivation. However, the long-term impact of VR in education is especially unknown. Most studies have been relatively short-term, typically lasting only a few weeks or months. While these studies have provided valuable insights into the immediate impact of VR, they cannot provide a comprehensive understanding of the long-term effects of VR in education. To address this, this thesis therefore recommends future research that looks at conducting longitudinal studies to better understand the benefits and challenges associated with VR in education.

Longitudinal studies are important as they can help to identify any unintended consequences or adverse effects that VR may have in the educational setting. For instance, VR may increase student engagement and motivation in the short term; however, it is possible that prolonged exposure to VR may have adverse effects, such as eye strain or motion sickness. Researchers would be able to identify any negative effects of VR and take steps to mitigate them if they conducted longitudinal studies that tracked the experiences of students over an extended period of time. These studies could also assist in answering questions regarding the long-term effects of VR on the learning outcomes of students. While some studies have shown that VR can enhance learning outcomes in the short term, it is unclear whether these effects will persist over time. Conducting longitudinal studies which monitor the academic progress of students would be beneficial to provide an answer as to whether the perceived and often postulated academic benefits can be sustained over the period of an entire course for example.

In addition to this, the studies could investigate how the use of VR affects the attitudes that students have towards learning as well as their engagement with the subject matter. Although VR has the potential to make education more interesting and interactive, it is not yet clear how this will translate into long-term changes in the attitudes and motivation of students. One of the studies (Chapter 5) already shows that the novelty factor of VR is starting to reduce, and the literature suggest many scholars make the incorrect assumption that novelty equals engagement. Longitudinal studies that track students' attitudes towards learning and engagement with the material over a significant period of time would provide valuable insights into the impact VR has on these factors.

The findings of these studies might also be able to assist in determining whether or not there are any discernible differences between the outcomes experienced by students who make use of virtual reality and those who do not. It is conceivable that some students might respond better to VR than other. Additionally, it is also possible that some topics will lend themselves better to VR than others. By conducting longitudinal studies, researchers would be able to identify any differences in outcomes between students in the above scenarios. This would allow the researchers to provide justification to educators on why VR may be beneficial in their practice, something educators often said was lacking when being asked to adopt new technology, as evidenced in Chapter 4.

8.7.5 Evaluate Approaches to VR World Building and Content

In taking the research output of Chapter 4 and the barriers educators face in respect of not being experienced in 3D modelling and VR world building, a user configuration mechanism within VERITAS was implemented. Users of the application could specify, by way of a JSON configuration file (see appendix C.1), the title of the mind mapping exercise, the images used for the tiles and number of tiles presented for the exercise. The file also allowed the enabling of the tutorial and logging, opening up the application to be used by other researchers. This configuration file was easy to edit and only had to be placed in a folder on the device headset. Work was ongoing to allow the application to retrieve the configuration file from a web URL so that even this small task was not required. For images, a web-based front end was being built that automatically resized images to be an appropriate ratio for use within the application. Unfortunately, the arrival of the pandemic curtailed this area of research prematurely. As detailed in the recommendations section above, this subject would certainly benefit from further study with a view to creating an all-encompassing PowerPoint like tool that supports VR world building and content population for novice users. In all likelihood, if this thesis were to start again with a blank canvas, it would look to use existing content creation platforms that have appeared since the inception of this thesis, namely VRChat, to design and build educational experiences that could be evaluated against learning outcomes and new and emerging pedagogical approaches.

8.7.6 Emerging Interaction Techniques in VR

At the start of this research, some mechanisms for interaction with VR were only just emerging and certainly not within the realm of any hardware device available to educators. One such mechanism that has seen rapid adoption for VR devices is eye tracking, now available on devices such as the Pico Neo 2 Eye. Eye tracking is mainly used in foveated rendering to improve visual fidelity, or rather reduced visual quality in areas where the user is not looking as a trade for additional rendering speed. This is analogous to audio compression systems such as ATRAC where audio information that a user couldn't hear (i.e., two overlayed frequencies) is dropped from a file to reduce file size with no noticeable reduction in audio quality. While this does improve the user experience, other researchers are looking into use these eye tracking sensors to provide new interaction schemes, such as using gaze to select occluded objects [234] or combining head tracking and gaze for object selection [233]. The latter research is however caveated that compared to existing base line interactions; a higher rate of initial selection errors is evident. Therefore, this thesis proposes that eye tracking is an interesting and valid research direction for future VR interaction research, especially considering the emphasis on accessibility within education.

Another interaction mechanism not available on the hardware this thesis targeted for this research when initiated was hand tracking. Hand tracking was introduced to the Oculus Quest in December 2019 as an experimental feature and later officially released in May 2020. Hand tracking on VR hardware has provided new opportunities for interactions by allowing users to interact with the virtual environment using their hands directly, without the need for handheld controllers. Specific interaction types affected by hand tracking include gesture-based interactions where hand tracking enables users to perform gestures, like pinching or waving, to interact with virtual objects or trigger specific actions within the VR environment. Rather than using ray casts or sticky controller binding, users can now pick up, move, and manipulate virtual objects with their hands, creating a more natural and immersive experience. Domains that have benefitted from hand tracking include artistic creation where hand tracking facilitates the creation of 3D art, sculptures, or drawings directly in the virtual environment using one's hands as the tools. Overall, hand tracking has made VR experiences more intuitive and engaging, opening up new possibilities for various applications in different fields. Existing mechanisms once considered common place now need to be re-evaluated in light of this technology appearing on many more devices.

Chapter 9

Conclusion

While VR (Virtual Reality) has long been recognised as a potentially significant tool to impact education and enhance student engagement in the learning process, barriers such as complex setups, high costs, and a lack of educational applications have hindered widespread adoption of this technology. Recent advances in VR technology have made low-cost untethered VR headsets more accessible and manageable for traditional classroom environments. However, it is essential to identify the exact use cases that benefit the learning process beyond the novelty factor of VR headsets and passive content consumption. Moreover, challenges in creating content for VR devices and the need for effective tools and frameworks for content management present additional obstacles to VR adoption in education.

Solving these problems is vital within education because students today are growing up with technology and expecting it to support their learning. By incorporating VR into the educational process, the technology can meet these expectations and align with the recommendations of government agencies, such as the 2015 FELTAG report, to improve the learner's experience. Additionally, identifying and developing use cases that foster active learning and higher cognitive processes in areas such as computational thinking, logic, and programming tasks can further enhance the educational benefits of VR technology.

This thesis investigated the potential of VR in education and its impact on student engagement, while addressing the barriers and challenges hindering its widespread adoption. This thesis details various studies, examining educators' perceptions of VR, assessing VR-based block-programming games, evaluating low-cost devices for supporting complex reflective tasks, and exploring the emergence of individual mind mapping strategies in a VR environment.

The exploratory study of educators' perception of VR reveals educators' excitement about VR's potential in education, but they need more information on its tangible benefits and have concerns about time, skill, and tool requirements for creating VR content. The assumption that VR is inherently more engaging than traditional activities may be flawed and could lead to overlooking other effective educational methods. This thesis recommends that education leaders consider the time and skill needed for VR integration, encourage developers to create domain-agnostic applications and resource repositories, and ensure tools for easy content creation. Institutions should clarify VR's educational benefits, consider its impact on behaviour management policies, and update guidance accordingly. By following these recommendations, education leaders can make informed decisions when implementing VR in their learning environments.

In the study of LogiBot, the implementation of computational thinking and engagement in the context of VR-based block-programming games is explored. the results suggest that students found the system both usable and enjoyable, although an assessment of learning outcomes was not conducted. Furthermore, it revealed that users' familiarity with VR no longer ensures that VR experiences are always more engaging compared to conventional desktop applications. This underscores the increasing importance of designing effective interactions within VR environments, particularly if VR-based learning tools such as LogiBot are to demonstrate advantages over traditional desktop platforms in terms of user experience and educational benefits.

For VERITAS, this study showcased that even with limited input controls, low-cost devices can effectively support intricate reflective tasks, particularly in the realm of mind mapping. The necessary interactions were executed with minimal errors. A crucial aspect to consider is the learnability of such applications. Although interactions might be complex, supporting them with audio feedback and a user interface that conveys the system's state can foster an environment where users grasp the system's functionality and progressively enhance their performance. Additionally, conducting mind mapping activities within VR seems to offer advantages, as several participants leveraged the immersive 3D space to manipulate their mind maps in ways unattainable with traditional 2D applications.

In the final study, it delved into the potential of VR to explore user behaviour when building mind maps within VR. The previous proof-of-concept VR mind mapping application VERITAS was utilised to examine this. Through the user study, the emergence of two distinct mind mapping strategies was observed: grouping and sequential. The discovery of these mapping strategies holds significant implications for future research in the realm of VR-based mind mapping, particularly within educational contexts. The findings are especially relevant for advancing collaboration-based paragogy, as they highlight the potential for VR to accommodate diverse learning and thinking styles, thereby fostering a more inclusive and engaging educational experience. The findings are also important for the designer of these applications so that they can consider and design for managing conflict within collaborative environments.

The key takeaway message from this research is that while educators recognise the potential of VR in education, there are concerns and challenges that need to be addressed for successful implementation. This includes providing more information on tangible benefits, considering the time and skill required for integration, and designing effective interactions within VR environments. Institutions should clarify VR's educational benefits and look to provide the tools and systems to build effective VR environments populated with high quality educational content. As VR experiences become less novel, it is crucial to ensure that they offer genuine educational value and are not chosen merely for their novelty. By addressing these challenges and focusing on the unique advantages VR offers, education leaders can make informed decisions when implementing VR in their learning environments and optimise its potential to complement and enhance traditional educational methods.

Chapter 10

Appendices

Appendix A - Statistics

Table A.1: Repeated measures ANOVA statistical analysis of Pre vs Post Activity completion times.

	F(1,23) = 33.07, $p < .05$	
2-way Interaction	Pre	Post
	$M = 194.54$s, $SD = 84.58$s	$M = 111.54$s, $SD = 53.64$s

Table A.2: Repeated measures ANOVA statistical analysis of task completion times (TCT) times by cohort.

	F(1,23) = 2.37, $p > .32$	
2-way Interaction	Sequential	Grouping
	$M = 336.70$s, $SD = 149.74$s	$M = 442.21$s, $SD = 174.69$s

Table A.3: Two-way repeated measures in one factor ANOVA statistical analysis of Pre vs Post Activity completion times by cohort.

3-way Interaction	F(1,22)=1.628, $p > .215$			
2-way Interaction	Pre		Post	
	F(1,22)=2.68, $p > .116$		F(1,22)=1.17, $p > .292$	
	Sequential	Grouping	Sequential	Grouping
	$M = 210.90$, $SD = 101.39$	$M = 182.86$, $SD = 72.03$	$M = 106.40$, $SD = 48.64$	$M = 115.21$, $SD = 58.46$

Table A.4: One-way ANOVA statistical analysis of first link creation time (normalised) by cohort.

	F(1,23)=15.99, $p < 0.05$	
2-way Interaction	Sequential	Grouping
	$M = 0.25$, $SD = .11$	$M = 0.40$, $SD = .20$

Table A.5: One-way ANOVA statistical analysis of first group creation time (normalised) by cohort.

	F(1,23)=15.99, $p < 0.05$	
2-way Interaction	Sequential	Grouping
	$M = 0.43$, $SD = .22$	$M = 0.17$, $SD = .10$

Table A.6: One-way ANOVA statistical analysis of bounding volume by cohort.

	$F(1,23)=2.461$, $p > .131$	
2-way Interaction	Sequential	Grouping
	$M = 65.53$, $SD = 28.39$	$M = 94.56$, $SD = 53.12$

Table A.7: One-way ANOVA statistical analysis of distance travelled by all tiles by cohort.

	$F(1,23)=8.39$, $p < 0.05$	
2-way Interaction	Sequential	Grouping
	$M = 55.68$, $SD = 23.23$	$M = 89.77$, $SD = 31.50$

Table A.7: One-way ANOVA statistical analysis of distance travelled by all tiles by cohort.

	$F(1,23)=5.16$, $p < 0.05$	
2-way Interaction	Sequential	Grouping
	$M = 15.80$, $SD = 8.33$	$M = 25.03$, $SD = 10.71$

Table A.8: One-way ANOVA statistical analysis of UEQ metrics by cohort.

Attractiveness		$F(1,23)=12.58$, $p < 0.05$	
	2-way Interaction	Sequential	Grouping
		$M = 2.08$, $SD = .54$	$M = 0.96$, $SD = .88$
Perspicuity		$F(1,23)=5.16$, $p > .517$	
	2-way Interaction	Sequential	Grouping
		$M = 1.00$, $SD = 1.14$	$M = .70$, $SD = 1.10$
Efficiency		$F(1,23)=5.16$, $p > .108$	
	2-way Interaction	Sequential	Grouping
		$M = 1.33$, $SD = 1.03$	$M = .54$, $SD = 1.10$
Dependability		$F(1,23)=5.16$, $p > .494$	
	2-way Interaction	Sequential	Grouping
		$M = 1.28$, $SD = .92$	$M = 1.00$, $SD = .98$
Stimulation		$F(1,23)=6.81$, $p < 0.05$	
	2-way Interaction	Sequential	Grouping
		$M = 2.00$, $SD = .70$	$M = 1.32$, $SD = .58$
Novelty		$F(1,23)=5.16$, $p > .409$	

	2-way Interaction	Sequential	Grouping
		$M = 1.45$, $SD = .93$	$M = 1.20$, $SD = .55$

Appendix B - Surveys

B.1 Qualtrics survey – Chapter four

D1 Please indicate your age.

- ◯ 18 - 20 (1)
- ◯ 21 - 25 (2)
- ◯ 26 - 30 (3)
- ◯ 31-40 (4)
- ◯ 41-50 (5)
- ◯ 51 - 60 (6)
- ◯ 61+ (7)

D2 What is your sex?

- ◯ Male (1)
- ◯ Female (2)
- ◯ Non-binary / third gender (3)
- ◯ Prefer not to say (4)

D3 To which gender identity do you most identify?

○ Male (1)

○ Female (2)

○ Transgender Male (3)

○ Transgender Female (4)

○ Gender Variant / Non-Conforming (5)

○ Not Listed (6) ____

○ Prefer not to say (7)

Page Break

D4 At what level do you teach at? Check all that apply.

▢ Primary (1)

▢ Secondary (2)

▢ FE (including apprenticeships) (3)

▢ HE (4)

▢ Non-academic (i.e. adult workplace training). (6)

▢ Other (5)

D5 Which geographic region do you usually teach in?

- United Kingdom (1)
- Africa (3)
- Asia (4)
- Central America (5)
- Europe (not UK) (2)
- North America (6)
- Oceana (7)
- South America (8)

D6 Do you hold a formal teaching (including teaching assistant) qualification?

- Yes (1)
- No (2)

Skip To: D8 If Do you hold a formal teaching (including teaching assistant) qualification? = No

Display This Question:

If Which geographic region do you usually teach in? = United Kingdom

D7 What teaching qualification do you hold? Check all that apply.

- ☐ Degree with QTS (1)
- ☐ PGCE with QTS (2)
- ☐ PGCE (Post compulsory 14+) (3)
- ☐ PGCHE (4)
- ☐ QTLS (5)
- ☐ PTLLS (6)
- ☐ CTLLS (7)
- ☐ DTLLS (8)
- ☐ Fellowship of the Higher Education Academy (9)
- ☐ Level 3 Teaching Assistant Diploma (11)
- ☐ Level 3 Award in Supporting Teaching and Learning in Schools (12)
- ☐ Level 2 Teaching Assistant Certificate (13)
- ☐ Level 2 Certificate in Supporting Teaching and Learning in Schools (14)
- ☐ Level 2 Award in Support Work in Schools (15)

☐ Other Level 2 / Level 3 teaching qualification (10)

☐ Other (16)

Page Break

D8 Do you teach full or part time?

○ Full time (1)

○ Part time (2)

Skip To: D10 If Do you teach full or part time? = Full time

D9 What is your part time ratio (i.e. 60% of full time)?

	0 10 20 30 40 50 60 70 80 90 100
1 ()	

D10 How many hours do you teach? I.e. not including planning and preparation time.

	0 5 10 15 20 25 30 35 40 45 50
1 ()	

Page Break

D11 Do you have any management responsibilities?

○ Yes (1)

○ No (2)

Skip To: D13 If Do you have any management responsibilities? = No

D12 Please list your management responsibilities. Check all that apply.

- ☐ Subject lead (1)
- ☐ Year head (2)
- ☐ TLR (3)
- ☐ Department lead (4)
- ☐ Head of school (5)
- ☐ Assistant head teacher (6)
- ☐ Deputy head teacher (7)
- ☐ Head teacher (8)
- ☐ Other (9)

D13 What subject do you mainly teach or what is your subject specialisation? Choose the closest match.

- ◯ Foreign Languages (1)
- ◯ English (2)
- ◯ Mathematics (3)
- ◯ Art (including Music, Fashion etc) (4)
- ◯ History (5)
- ◯ Geography (6)
- ◯ Science (Physics, Chemistry and Biology) (7)
- ◯ Computer Science (8)
- ◯ Design Technology (including Wood working etc) (9)
- ◯ Physical Education (10)
- ◯ Religious Education / Citizenship (11)
- ◯ Engineering (including Architecture) (13)
- ◯ Law (12)
- ◯ Drama (14)
- ◯ Construction (Plumbing, Electrician, Brick Laying etc) (15)
- ◯ Sociology (18)
- ◯ Economics (19)

○ Medicine (including Nursing) (20)

○ Psychology (21)

○ Other Humanities (i.e. Politics, Philosophy etc) (16)

○ Other (17)

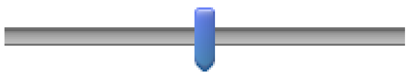
End of Block: Demographics

Start of Block: Resources

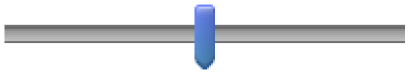
R0
This section of the survey will collect your experiences of and attitudes to resources creation within education

---

R1 How many hours per week are you allocated for resource creation (from scratch)?

	0 2 4 6 8 10 12 14 16 18 20
1 ()	

R2 How many hours do you ACTUALLY spend on creating resources (from scratch) - including in your own time?

	0 2 4 6 8 10 12 14 16 18 20
1 ()	

R3 Please identify some of the typical resources you regularly create? Tick all that apply.

- ☐ Illustrations/Diagrams/Images (1)
- ☐ Worksheets (2)
- ☐ Quizzes (printed) (3)
- ☐ Quizzes (online) (4)
- ☐ Websites / Wikis / Blogs (5)
- ☐ Slideshows/Presentations (6)
- ☐ Games (apps/online) (7)
- ☐ Games (printed) (8)
- ☐ Graphs (11)
- ☐ Flow charts (12)
- ☐ Journals (13)
- ☐ Photos (14)
- ☐ Tutorials / 'how to' guides / Instruction manuals (16)
- ☐ Revision guides (17)
- ☐ Social media content (Facebook, Twitter etc) (18)

- ☐ Videos (online such as YouTube etc) (19)
- ☐ Videos (not online) (20)
- ☐ Textbooks (21)
- ☐ Online learning platform pages (Moodle etc) (23)
- ☐ Lesson plans (24)
- ☐ Module plans/specifications (BTEC module, Level 4 module) (25)
- ☐ Academic courses (i.e. BTEC, degree etc) (26)
- ☐ Skill based training courses (27)
- ☐ Syllabus (29)
- ☐ Databases (30)
- ☐ Case studies (31)
- ☐ Animations (32)
- ☐ 3D models (33)
- ☐ Physical objects (i.e. wood work, metal work, clay model etc) (34)
- ☐ Assembly kits (i.e. Lego Mindstorm, Raspberry Pi, microBit etc) (35)

☐ Other (9)

Skip To: R5 If Please identify some of the typical resources you regularly create? Tick all that apply. != Other

R4 You selected "Other". Please list the types of resources you create that were not listed.

____

____

____

____

____

Page Break

R5 Do you create resources in collaboration with other educators?

○ Yes (1)

○ No (2)

Skip To: R7 If Do you create resources in collaboration with other educators? = No

R6 How frequently do you create resources in collaboration with other educators?

○ More than once a week (1)

○ Once every two weeks (2)

○ Once a month (3)

○ Once every two to six months (4)

○ Less than once every six months (5)

Skip To: R9 If How frequently do you create resources in collaboration with other educators? = More than once a week

Skip To: R9 If How frequently do you create resources in collaboration with other educators? = Once every two weeks

Skip To: R9 If How frequently do you create resources in collaboration with other educators? = Once a month

R7 What are the reasons you don't collaborate frequently with other educators to create resources? Check all that apply.

- ▢ No need / not required to (1)
- ▢ Not enough time (2)
- ▢ Tools / technology too difficult to use (3)
- ▢ Planning time does not sync with colleagues (4)
- ▢ I prefer to work on my own (5)
- ▢ I don't know anyone else with the expertise in my subject (6)
- ▢ Other (7)

Skip To: R9 If What are the reasons you don't collaborate frequently with other educators to create resources? C... != Other

R8 You selected "Other". Please can you list the reason(s) you don't collaborate with other educators to create resources?

____

____

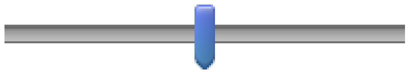
____

____

____

Page Break

R9 How many hours per week do you spend on sourcing existing resources from within your organisation?

	0 2 4 6 8 10 12 14 16 18 20
1 ()	

Skip To: R11 If How many hours per week do you spend on sourcing existing resources from within your organisation? [1] <=

R10 Please name some of the typical resources you source from within your organisation?

____

____

____

____

____

Page Break

R11 Do you source resources from any external providers?

◯ Yes (1)

◯ No (2)

Skip To: R17 If Do you source resources from any external providers? = No

R12 How many hours per week to you spend sourcing resources from external providers?

	0 2 4 6 8 10 12 14 16 18 20
1 ()	

R13 Where do you source external resources from (please list your top three)?

◯ 1 (4) ____

◯ 2 (5) ____

◯ 3 (7) ____

R14 How do you find external resources?

____

____

____

____

____

R15 Do you modify external resources?

○ Yes (1)

○ No (2)

Skip To: R17 If Do you modify external resources? = No

R16 In what way do you typically modify external resources?

____

____

____

____

____

Page Break

R17 When creating your own resources from scratch, please list the top three tools you use.

○ Tool 1 (1) ____

○ Tool 2 (2) ____

○ Tool 3 (3) ____

Carry Forward All Choices - Entered Text from "When creating your own resources from scratch, please list the top three tools you use."

R18 Please rank the tools in order of preference (drag the boxes to re-order, 1 being the highest/most preferred).

______ Tool 1 (1)

______ Tool 2 (2)

______ Tool 3 (3)

R19 For your preferred tool, what does it do best?

____

____

____

____

R20 And what does it do worst?

____

____

____

____

____

Page Break

R21 Is there a type of resource that you need to create that isn't currently possible / difficult to create with your current tools?

◯ Yes (1)

◯ No (2)

Skip To: End of Block If Is there a type of resource that you need to create that isn't currently possible / difficult to... = No

R22 Please describe the resource.

____

____

____

R23 Please describe the process of how you would like to create the resource.

End of Block: Resources

Start of Block: Pedagogy

P0
This section of the survey will collect your views on pedagogical approaches

P1 Do you actively and consciously use pedagogical approaches in your teaching? I.e. Behaviourism, Social Constructivism, Connectivism etc.

- ○ Yes (5)
- ○ No (6)

Skip To: P5 If Do you actively and consciously use pedagogical approaches in your teaching? I.e. Behaviourism, S... = No

P2 Do you have a preferred pedagogical approach?

- ◯ Yes (1)
- ◯ No (2)

Skip To: P5 If Do you have a preferred pedagogical approach? = No

P3 What is your preferred pedagogical approach? Either the name of the approach or the theorist (i.e. Piaget, Thorndyke etc) is fine.

____

____

____

____

____

P4 Do you have a preferred pedagogical technique? I.e. Socratic questioning, problem based learning, debate, flipped learning etc. List as many as you like or type 'none'.

____

____

____

Skip To: End of Block If Condition: Do you have a preferred ped... Is Not Empty. Skip To: End of Block.

P5 Why do you not use or have a preferred pedagogical approach for your teaching? Check all that apply.

- ☐ Not applicable in my institution (1)
- ☐ Not required in my teaching (2)
- ☐ No time to research appropriate pedagogies (3)
- ☐ I don't understand the pedagogical approaches (4)
- ☐ My pedagogical approach is dictated by my institution (5)
- ☐ I don't know which pedagogical approach I prefer (6)
- ☐ I use multiple pedagogical approaches (7)
- ☐ I prefer to use my intuition (9)
- ☐ I don't feel it would improve my teaching (10)
- ☐ A lot of the approaches are outdated (11)
- ☐ Pedagogical approaches are not relevant to my teaching (12)
- ☐ Other (8)

Skip To: End of Block If Why do you not use or have a preferred pedagogical approach for your teaching? Check all tha... != Other

P6 Please type the reason(s) for selecting 'Other".

____

____

____

____

____

End of Block: Pedagogy

Start of Block: VR

VR0
This section of the survey will collect your views on Virtual Reality use within education

---

VR1 When being asked to use new technology (e.g. Virtual Reality) to teach, what concerns you the most?

____

____

____

____

____

VR2 How do you think this could be resolved?

VR3 Imagine your institution told you it would be mandatory to teach using Virtual Reality devices in the new term. Select up to three words from Plutchik's emotion wheel below to describe your reaction.

	Dislike (1)	Neutral (2)	Like (3)
Region #1 (1)			
Region #2 (2)			
Region #3 (3)			
Region #4 (4)			
Region #5 (5)			
Region #6 (6)			
Region #7 (7)			
Region #8 (8)			
Region #9 (9)			
Region #10 (10)			
Region #11 (11)			
Region #12 (12)			
Region #13 (13)			
Region #14 (14)			
Region #15 (15)			
Region #16 (16)			

Region #17 (17)

Region #18 (18)

Region #19 (19)

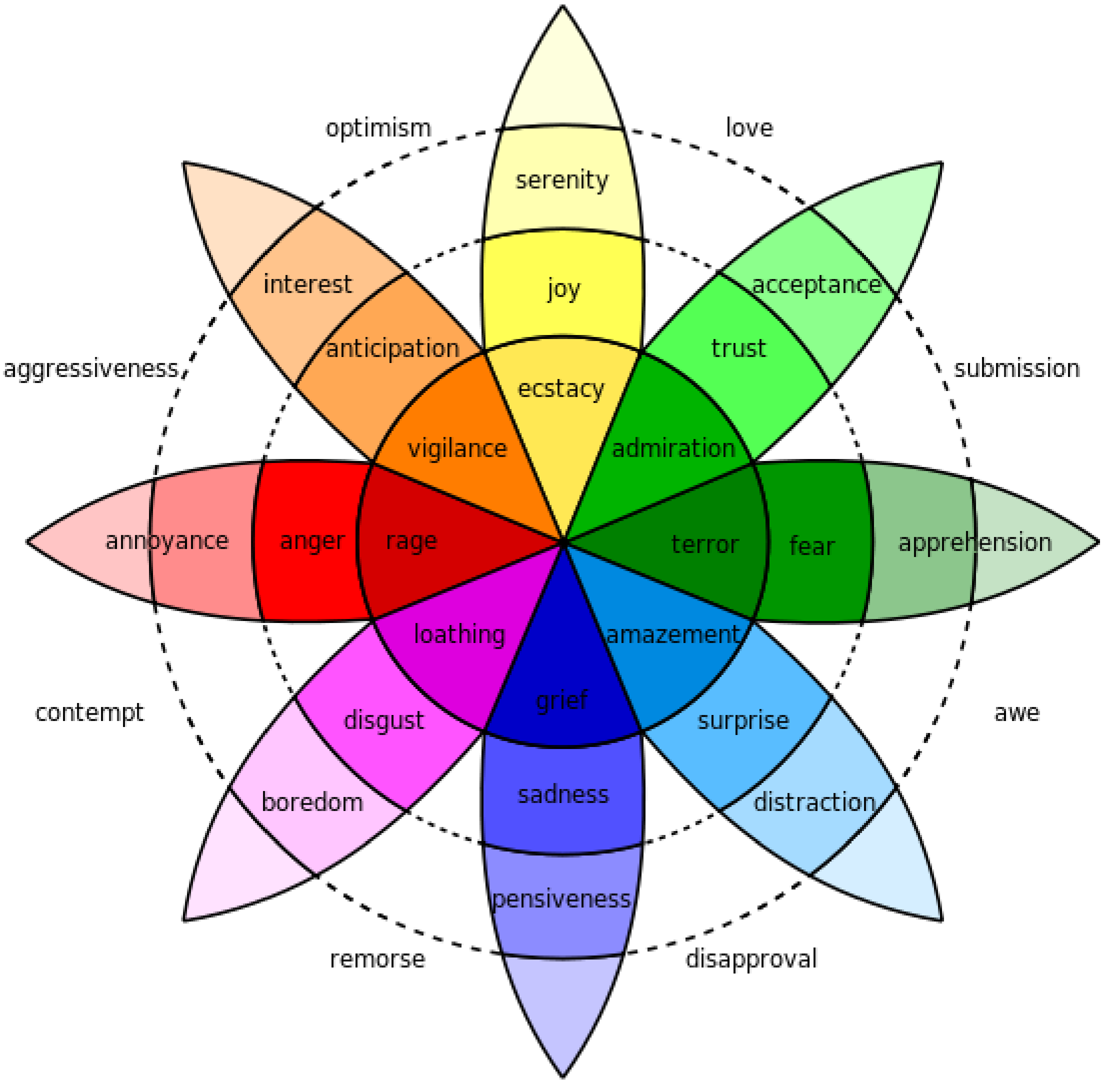
Region #20 (20)

Region #21 (21)

Region #22 (22)

Region #23 (23)

Region #24 (24)


optimism
love
serenity
interest
joy
acceptance
anticipation
trust
aggressiveness
submission
ecstacy
vigilance
admiration
annoyance
anger
rage
terror
fear
apprehension
loathing
amazement
contempt
awe
grief
disgust
surprise
sadness
boredom
distraction
pensiveness
remorse
disapproval

Page Break

VR4 In your teaching, what kind of educational activities do you think you could/would use VR for? Check all that apply.

- ☐ Lectures (1)
- ☐ Videos (2)
- ☐ Demonstrations (3)
- ☐ Slides (4)
- ☐ Podcasts (5)
- ☐ Whiteboard (6)
- ☐ Worksheets (7)
- ☐ Simulations (8)
- ☐ Games (9)
- ☐ Problem solving (10)
- ☐ Case studies (11)
- ☐ Research (12)
- ☐ Ideation (13)
- ☐ Classifying (14)

- ☐ Experiments (15)
- ☐ Building (16)
- ☐ Group projects (17)
- ☐ Role playing (18)
- ☐ Co-operative games (19)
- ☐ Debates (20)
- ☐ Jigsaw (21)
- ☐ Concept mapping (22)
- ☐ Brain storming (23)
- ☐ Mind-mapping (24)
- ☐ Other (25)

Skip To: VR6 If In your teaching, what kind of educational activities do you think you could/would use VR for? Ch... != Other

VR5 You selected "Other". Please list any additional activities you would use VR for here.

____

____

Page Break

VR6 What main educational benefit do you think VR can provide?

VR7 What do you think are the main challenges in using VR in the classroom?

Page Break

Carry Forward All Choices - Displayed & Hidden from "Please identify some of the typical resources you regularly create? Tick all that apply."

VR8 What resources (your own or sourced elsewhere) do you think would be suited for use within VR educational activities? Check all that apply.

- [ ] Illustrations/Diagrams/Images (1)
- [ ] Worksheets (2)
- [ ] Quizzes (printed) (3)
- [ ] Quizzes (online) (4)
- [ ] Websites / Wikis / Blogs (5)
- [ ] Slideshows/Presentations (6)
- [ ] Games (apps/online) (7)
- [ ] Games (printed) (8)
- [ ] Graphs (9)
- [ ] Flow charts (10)
- [ ] Journals (11)
- [ ] Photos (12)
- [ ] Tutorials / 'how to' guides / Instruction manuals (13)

- ☐ Revision guides (14)
- ☐ Social media content (Facebook, Twitter etc) (15)
- ☐ Videos (online such as YouTube etc) (16)
- ☐ Videos (not online) (17)
- ☐ Textbooks (18)
- ☐ Online learning platform pages (Moodle etc) (19)
- ☐ Lesson plans (20)
- ☐ Module plans/specifications (BTEC module, Level 4 module) (21)
- ☐ Academic courses (i.e. BTEC, degree etc) (22)
- ☐ Skill based training courses (23)
- ☐ Syllabus (24)
- ☐ Databases (25)
- ☐ Case studies (26)
- ☐ Animations (27)
- ☐ 3D models (28)
- ☐ Physical objects (i.e. wood work, metal work, clay model etc) (29)

☐ Assembly kits (i.e. Lego Mindstorm, Raspberry Pi, microBit etc) (30)

☐ Other (31)

Skip To: VR10 If Condition: Other Is Not Selected. Skip To: Thinking about the tools you currentl....

VR9 You selected "Other". Please list the types of resources you think would be suited for use in VR that were not listed.

____

____

____

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____

Page Break

VR10 Thinking about the tools you currently use, can you describe the (existing or new) process you might follow to populate these VR activities with your chosen resources?

____

____

____

____

____

VR11 How comfortable would you be with the process you have described?

- ◯ Extremely comfortable (1)
- ◯ Somewhat comfortable (2)
- ◯ Neither comfortable nor uncomfortable (3)
- ◯ Somewhat uncomfortable (4)
- ◯ Extremely uncomfortable (5)

VR12 Can you describe how you might make this process better?

____

____

____

____

B.2 User Engagement Scale (UES) – Chapter four

Instructions for administrators: When administering the UES and UES-SF, all items should be randomised and dimension identifiers (e.g., 'Focused Attention or FA') should not be visible to participants. Below we provide general instructions to participants than can be modified to suit the study context; the five-point rating scale should be used to allow for comparisons across studies/sampled populations. The wording of the questions may be modified to your context of use. For example, item PU.1 "I felt frustrated while using this Application X" may be reworded to "I felt frustrated while using this search engine."

Instructions for respondents: The following statements ask you to reflect on your experience of engaging with Application X or "this study". For each statement, please use the following scale to indicate what is most true for you.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

User Engagement Scale Long Form (UES-LF).

FA.1 I lost myself in this experience.

FA.2 I was so involved in this experience that I lost track of time.

FA.3 I blocked out things around me when I was using Application X.

FA.4 When I was using Application X, I lost track of the world around me.

FA.5 The time I spent using Application X just slipped away.

FA.6 I was absorbed in this experience.

FA.7 During this experience I let myself go.

PU.1 I felt frustrated while using this Application X.

PU.2 I found this Application X confusing to use.

PU.3 I felt annoyed while using Application X.

PU.4 I felt discouraged while using this Application X.

PU.5 Using this Application X was taxing.

PU.6 This experience was demanding.

PU.7 I felt in control while using this Application X.

PU.8 I could not do some of the things I needed to do while using Application X.

AE.1 This Application X was attractive.

AE.2 This Application X was aesthetically appealing.

AE.3 I liked the graphics and images of Application X.

AE.4 Application X appealed to be visual senses.

AE.5 The screen layout of Application X was visually pleasing.

RW.1 Using Application X was worthwhile.

RW.2 I consider my experience a success.

RW.3 This experience did not work out the way I had planned.

RW.4 My experience was rewarding.

RW.5 I would recommend Application X to my family and friends.

RW.6 I continued to use Application X out of curiosity.

RW.7 The content of Application X incited my curiosity.

RW.8 I was really drawn into this experience.

RW.9 I felt involved in this experience.

RW.10 This experience was fun.

B.3 User Experience Questionnaire (UEQ) – Chapters four and five

Please make your evaluation now.

For the assessment of the product, please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may apply to the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Example:

attractive	○	⊗	○	○	○	○	○	unattractive

This response would mean that you rate the application as more attractive than unattractive.

Please decide spontaneously. Don’t think too long about your decision to make sure that you convey your original impression.

Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line.

Additionally, after the survey there is a text box that you may complete to convey any ideas or messages to the researcher that you may think relevant to your experience.

It is your personal opinion that counts. Please remember: there is no wrong or right answer!

Please assess the product now by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

If you have any ideas or messages that you would like to convey to the researcher regarding your experience, please write them here. You can continue overleaf if you need more room:-

B.4 Simulator Sickness Questionnaire (SSQ) – Chapters five and six.

Pre-exposure Simulator Sickness Questionnaire

SYMPTOM CHECKLIST

Pre-exposure instructions: please fill in this questionnaire. Circle below if any of the symptoms apply to you now. You will be asked to fill this again after the experiment

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Boredom	None	Slight	Moderate	Severe
4. Drowsiness	None	Slight	Moderate	Severe
5. Headache	None	Slight	Moderate	Severe
6. Eyestrain	None	Slight	Moderate	Severe
7. Difficulty focusing	None	Slight	Moderate	Severe
8. Salivation increase	None	Slight	Moderate	Severe
Salivation decrease	None	Slight	Moderate	Severe
9. Sweating	None	Slight	Moderate	Severe
10. Nausea	None	Slight	Moderate	Severe
11. Difficulty concentrating	None	Slight	Moderate	Severe
12. Mental depression	No	Yes (Slight	Moderate	Severe)
13. "Fullness of the head"	No	Yes (Slight	Moderate	Severe)
14. Blurred vision	No	Yes (Slight	Moderate	Severe)
15. Dizziness eyes open	No	Yes (Slight	Moderate	Severe)
Dizziness eyes close	No	Yes (Slight	Moderate	Severe)
16. Vertigo	No	Yes (Slight	Moderate	Severe)
17. Visual flashbacks*	No	Yes (Slight	Moderate	Severe)
18. Faintness	No	Yes (Slight	Moderate	Severe)

19. Aware of breathing	No	Yes (Slight	Moderate	Severe)
20. Stomach awareness	No	Yes (Slight	Moderate	Severe)
21. Loss of appetite	No	Yes (Slight	Moderate	Severe)
22. Increased appetite	No	Yes (Slight	Moderate	Severe)
23. Desire to move bowels	No	Yes (Slight	Moderate	Severe)
24. Confusion	No	Yes (Slight	Moderate	Severe)
25. Burping	No	Yes (Slight	Moderate	Severe)
26. Vomiting	No	Yes (Slight	Moderate	Severe)
27. Other	No	Yes (Slight	Moderate	Severe)

Appendix C – VERITAS Development

D.1 VERITAS Configuration File – Chapter 7


```json
{
  "product": "Veritas config file",
  "version": 1.1,
  "releaseDate": "2022-08-07T00:00:00.000Z",
  "configVariables": [{
    "tutorial": true,
    "postActivity": false,
    "logging": true
  }],
  "repositories": [
    {
      "title": "Disney",
      "url": "http://co-veritas.co.uk/Veritas/Disney/",
      "noOfTiles": 10
    },
    {
      "title": "Capital Cities",
      "url": "http://co-veritas.co.uk/Veritas/Geography/",
      "noOfTiles": 13
    },
    {
      "title": "Solar System",
      "url": "http://co-veritas.co.uk/Veritas/Space/",
      "noOfTiles": 9
    }
  ]
}
```

Appendix D – Ethics Documentation

E.1 Example Participant information sheet (interviews) – Chapter 3

Participant information sheet

For further information about how Lancaster University processes personal data for research purposes and your data rights please visit our webpage: www.lancaster.ac.uk/research/data-protection

I am a PhD student at Lancaster University and I would like to invite you to take part in a research study about resource creation in education.

Please take time to read the following information carefully before you decide whether you wish to take part.

What is the study about?

The aim of the study is to investigate how educators create educational resources, the pressures this involves and best practices in the field.

Why have I been invited?

I have approached you because you are an active educational practitioner that uses technology in your lessons and might be interested in influencing future toolkits used to assist in the creation of educational resources.

I would be very grateful if you would agree to take part in this study.

What will I be asked to do if I take part?

If you decided to take part, this would consist of a 30 to 45 minute semi-structured interview asking you about your thoughts and opinions on creating educational resources and the tools used to do so. The interview will also collect rudimentary demographics such as the sector you teach in, how long you spend creating resources etc. The type of data we will be recording will include written notes and audio recordings via dictaphone.

What are the possible benefits from taking part?

Taking part in this study will allow you to share your experiences of creating resources in an educational context. The output from this study could lead to improvements in the types of tools available to assist educators in creating resources.

Do I have to take part?

No. It's completely up to you to decide whether or not you take part. Your participation is voluntary and you are free to withdraw at any time, without giving any reason.

What if I change my mind?

As explained above, you are free to withdraw at any time and if you want to withdraw, I will extract any data you contributed to the study and destroy it. Data means the information, notes and audio etc. that you and other participants will have shared with me. However, it is difficult and often impossible to take out data from one specific participant when this has already been anonymised or pooled together with other people's data. Therefore, you can only withdraw prior to any collected data being anonymised.

What are the possible disadvantages and risks of taking part?

The study will require you to commit approximately 30 to 45 minutes of your time.

There are no other anticipated risks.

Will my data be identifiable?

After the interviews are completed only I, the researcher conducting this study, and my supervisor (Dr. Abhijit Karnik) will have access to the data you share with me.

I will keep all personal information about you (e.g. your name and other information about you that can identify you) confidential, that is I will not share it with others. I will anonymise hard copies of any data. This means that I remove any personal information from the data (written notes and audio recordings).

How will my data be stored?

Your data will be stored in encrypted files (that is no-one other than me, the researcher, and my supervisor, Dr. Abhijit Karnik, will be able to access them) and on password-protected computers.

I will store hard copies of any written notes securely in locked cabinets in my supervisors office.

I will keep data that can identify you separately from non-personal information (e.g. your views on a specific topic).

In accordance with University guidelines, I will keep the data securely for a minimum of ten years.

How will we use the information you have shared with us and what will happen to the results of the research study?

I will use the data you have shared with only in the following ways:
I will use it for academic purposes only. This will include publishing to academic journals and/or my Ph.D thesis. I may also present the results of my study at academic conferences

When writing up the findings from this study, I would like to reproduce some of the views and ideas you shared with me. When doing so, I will only use anonymised quotes (e.g. from your interview responses), so that although I will use your exact words, you cannot be identified in our publications.

This study is funded by Lancaster University. The funder expects me to make my data available for future research and use by other researchers. I will only share anonymised data in this way and will exclude all personal data from archiving. The Lancaster University PURE system will be utilised to host and share the dataset output of this study.

Who has reviewed the project?

This study has been reviewed and approved by the Faculty of Science and Technology Research Ethics Committee.

What if I have a question or concern?

If you have any queries or if you are unhappy with anything that happens concerning your participation in the study, please contact myself in writing to:-

Robert Sims
Room A42
InfoLab21
Bailrigg
Lancaster
LA1 4YW

Or via email to:

r.sims2@Lancaster.ac.uk

If you have any concerns or complaints that you wish to discuss with a person who is not directly involved in the research, you can also contact:

Adrian Friday
Room C51
InfoLab21
Bailrigg
Lancaster
LA1 4YW

Or via email to:-

a.friday@lancaster.ac.uk

Thank you for considering your participation in this project.

Chapter 11

References

[1] Abdullah, J. et al. 2019. Virtual reality to improve group work skill and self-directed learning in problem-based learning narratives. *Virtual Reality*. 0123456789 (2019). DOI:https://doi.org/10.1007/s10055-019-00381-1.

[2] Abi-El-Mona, I. and Adb-El-Khalick, F. 2008. The Influence of Mind Mapping on Eighth Graders' Science Achievement. *School Science and Mathematics*. 108, 7 (2008), 298–312. DOI:https://doi.org/10.1111/j.1949-8594.2008.tb17843.x.

[3] Accot, J. and Zhai, S. 2002. More than dotting the i's --- foundations for crossing-based interfaces. *Proceedings of the SIGCHI conference on Human factors in computing systems*. 4 (2002), 73. DOI:https://doi.org/10.1145/503376.503390.

[4] Ahmed, S. 2019. A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management. *Organization, Technology and Management in Construction: an International Journal*. 11, 1 (Feb. 2019), 1839–1852. DOI:https://doi.org/10.2478/otmcj-2018-0012.

[5] Ahn, J. and Clegg, T. 2017. Human-Computer Interaction and Education. *The Wiley Handbook of Human Computer Interaction*. John Wiley & Sons, Ltd. 821–830.

[6] Aisbitt, S. and Sangster, A. 2005. Using internet-based on-line assessment: A case study. *Accounting Education*. 14, 4 (Dec. 2005), 383–394. DOI:https://doi.org/10.1080/06939280500346011.

[7] Alhalabi, W. 2016. Virtual reality systems enhance students' achievements in engineering education. *Behaviour & Information Technology*. 35, 11 (Nov. 2016), 919–925. DOI:https://doi.org/10.1080/0144929X.2016.1212931.

[8] Almstrum, V.L. et al. 2006. Concept inventories in computer science for the topic discrete mathematics. *Working group reports on ITiCSE on Innovation and technology in computer science education - ITiCSE-WGR '06* (New York, New York, USA, 2006), 132.

[9] Alvarez, R. and Urla, J. 2002. Tell me a good story. *ACM SIGMIS Database: the DATABASE for Advances in Information Systems*. 33, 1 (Feb. 2002), 38–52. DOI:https://doi.org/10.1145/504350.504357.

[10] Anderson, L.W. and Krathwohl, D.R. 2001. *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Longman,.

[11] Arksey, H. and Knight, P.T. 1999. *Interviewing for social scientists: An introductory resource with examples*. Sage.

[12] Arvanitis, T.N. et al. 2009. Human factors and qualitative pedagogical evaluation of a mobile augmented reality system for science education used by learners with physical disabilities. *Personal and Ubiquitous Computing*. 13, 3 (2009), 243–250. DOI:https://doi.org/10.1007/s00779-007-0187-7.

[13] Avery, J. et al. 2018. Bloom ' s Taxonomy : Original and revised. *Proc. of CHI*. 3, 1-A(E) (2018), 1–13. DOI:https://doi.org/10.1016/j.tcb.2010.02.004.

[14] Azmandian, M. et al. 2016. A Demonstration of Haptic Retargeting. *Proceedings of the 2016 ACM on Interactive Surfaces and Spaces* (New York, New York, USA, 2016), 501–504.

[15] Balım, A.G. 2013. The effect of mind-mapping applications on upper primary students' success and inquiry-learning skills in science and environment education. *International Research in Geographical and Environmental Education*. 22, 4 (Nov. 2013), 337–352. DOI:https://doi.org/10.1080/10382046.2013.826543.

[16] Barab, S.A. and Luehmann, A.L. 2003. Building sustainable science curriculum: Acknowledging and accommodating local adaptation. *Science Education*. 87, 4 (2003), 454–467.

[17] Bau, D. et al. 2017. Learnable programming. *Communications of the ACM*. 60, 6 (May 2017), 72–80. DOI:https://doi.org/10.1145/3015455.

[18] Becta, A. 2004. A review of the research literature on barriers to the uptake of ICT by teachers. *London, UK, BECTA) http://publications. becta. org. uk/display. cfm*. (2004).

[19] Beel, J. and Langer, S. 2011. An exploratory analysis of mind maps. *Proceedings of the 11th ACM symposium on Document engineering* (New York, New York, USA, 2011), 81.

[20] Bell, J.T. and Fogler, H.S. 1995. The investigation and application of virtual reality as an educational tool. *Proceedings of the American Society for Engineering Education Annual Conference* (1995), 1718–1728.

[21] Benford, S. et al. 1994. Managing Mutual Awareness in Collaborative Virtual Environments. August 1994 (1994), 223–236. DOI:https://doi.org/10.1142/9789814350938_0018.

[22] Benko, H. et al. 2016. NormalTouch and TextureTouch. *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (New York, New York, USA, 2016), 717–728.

[23] Bitrián, P. et al. 2021. Enhancing user engagement: The role of gamification in mobile apps. *Journal of Business Research*. 132, (Aug. 2021), 170–185. DOI:https://doi.org/10.1016/j.jbusres.2021.04.028.

[24] Bloom, S. 1956. *Taxonomy of Educational Objectives*. Mckay.

[25] Bochenek, G.M. and Ragusa, J.M. 2004. Improving integrated project team interaction through virtual (3d) collaboration. *EMJ - Engineering Management Journal*. 16, 2 (2004), 3–12. DOI:https://doi.org/10.1080/10429247.2004.11415243.

[26] Bogicevic, V. et al. 2019. Virtual reality presence as a preamble of tourism experience: The role of mental imagery. *Tourism Management*. 74, (Oct. 2019), 55–64. DOI:https://doi.org/10.1016/j.tourman.2019.02.009.

[27] Börner, K. 2001. iScape: A collaborative memory palace for digital library search results. *Proceedings of the 2001 International Conference on Human-Computer Interaction*. 1, 1998 (2001), 1160--1164.

[28] Bower, M. 2006. Virtual classroom pedagogy. *Proceedings of the 37th SIGCSE technical symposium on Computer science education - SIGCSE '06* (New York, New York, USA, 2006), 148.

[29] Bowman, D. a. et al. 1999. Testbed Evaluation of Virtual Environment Techniques Interaction. *Symposium on Virtual Reality Software and Technology, VRST 1999*. (1999), 26–33. DOI:https://doi.org/10.1145/323663.323667.

[30] Bowman, D.A. and McMahan, R.P. 2007. Virtual Reality: How Much Immersion Is Enough? *Computer*. 40, 7 (Jul. 2007), 36–43. DOI:https://doi.org/10.1109/MC.2007.257.

[31] van Boxtel, C. et al. 2000. Collaborative learning tasks and the elaboration of conceptual knowledge. *Learning and Instruction*. 10, 4 (Aug. 2000), 311–330. DOI:https://doi.org/10.1016/S0959-4752(00)00002-5.

[32] Boyd, L.E. et al. 2018. vrSocial. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (New York, New York, USA, 2018), 1–12.

[33] Boysen, G.A. 2021. Lessons (not) learned: The troubling similarities between learning styles and universal design for learning. *Scholarship of Teaching and Learning in Psychology*. (Jun. 2021). DOI:https://doi.org/10.1037/stl0000280.

[34] Braun, V. and Clarke, V. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology*. 3, 2 (2006), 77–101. DOI:https://doi.org/10.1191/1478088706qp063oa.

[35] Bricken, M. and Byrne, C.M. 1993. *Summer Students in Virtual Reality*. Academic Press, Inc.

[36] Brinkman, W.-P. et al. 2008. HCI for technology enhanced learning. *People and Computers XXII Culture, Creativity, Interaction 22*. (2008), 185–186.

[37] Buran, A. and Filyukov, A. 2015. Mind Mapping Technique in Language Learning. *Procedia - Social and Behavioral Sciences*. 206, November (2015), 215–218. DOI:https://doi.org/10.1016/j.sbspro.2015.10.010.

[38] Carbonilla Gorra, V. and Bhati, S.S. 2016. Students' perception on use of technology in the classroom at higher education institutions in Philippines. (2016).

[39] Chandramouli, M. et al. 2014. A fun-learning approach to programming: An adaptive Virtual Reality (VR) platform to teach programming to engineering students. *IEEE International Conference on Electro/Information Technology* (Jun. 2014), 581–586.

[40] Chang, C.Y. and Hwang, G.J. 2019. Trends in digital game-based learning in the mobile era: a systematic review of journal publications from 2007 to 2016. *International Journal of Mobile Learning and Organisation*. 13, 1 (2019), 68. DOI:https://doi.org/10.1504/IJMLO.2019.096468.

[41] Chauvergne, E. et al. 2023. User Onboarding in Virtual Reality: An Investigation of Current Practices. *2023 CHI Conference on Human Factors in Computing Systems* (2023).

[42] Chen, C.J. et al. 2005. Are learning styles relevant to virtual reality? *Journal of research on technology in education*. 38, 2 (2005), 123–141.

[43] Chen, Y.S. et al. 2003. A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted Learning*. 19, 3 (Sep. 2003), 347–359. DOI:https://doi.org/10.1046/j.0266-4909.2003.00036.x.

[44] Chik, V. et al. 2007. Intelligent Mind-mapping. *Conference: Proceedings of the 2007 Australasian Computer-Human Interaction Conference* (2007), 195–198.

[45] Clark, B. 2013. *Moving the technology into the AU/LBS classroom project: Blended delivery: A literature review*. College Sector Committee for Adult Upgrading.

[46] Clark, R.C. and Mayer, R.E. 2016. *E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning*. John Wiley & Sons.

[47] Classen, S. et al. 2011. Driving simulator sickness: An evidence-based review of the literature. *American Journal of Occupational Therapy*. 65, 2 (2011), 179–188. DOI:https://doi.org/10.5014/ajot.2011.000802.

[48] Coding Leap LLC 2019. NODA.

[49] Cohen, L. et al. 2013. *Research Methods in Education*. Routledge.

[50] Collins, A. et al. 1991. Cognitive apprenticeship: Making thinking visible. *American Educator*. 15, 3 (1991), 6–11.

[51] Cooke, N.A. 2010. Becoming an Andragogical Librarian: Using Library Instruction as a Tool to Combat Library Anxiety and Empower Adult Learners. *New Review of Academic Librarianship*. 16, 2 (Oct. 2010), 208–227. DOI:https://doi.org/10.1080/13614533.2010.507388.

[52] Cooper, S. et al. 2000. Alice: a 3-D tool for introductory programming concepts. *Journal of Computing Sciences in Colleges*. 15, 5 (2000), 107–116.

[53] Corneli, J. and Danoff, C.J. 2011. Paragogy: Synergizing individual and organizational learning. *the 1st International Conference on Learning Analytics and Knowledge* (2011).

[54] Cox, D.A. et al. 2004. Technology-enhanced learning and teaching in higher education: what is "enhanced" and how do we know? A critical literature review. *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW*. 39, 6 (2004), 72–80. DOI:https://doi.org/10.1145/3015455.

[55] Crearie, L. 2013. Human computer interaction (HCI) factors in technology enhanced learning. *ICICTE 2013*. L. Morris and C. Tsolakidis, eds. International Conference on Information Communication Technologies in Education. 99–108.

[56] Cummings, J.J. and Bailenson, J.N. 2016. How Immersive Is Enough? A Meta-Analysis of the Effect of Immersive Technology on User Presence. *Media Psychology*. 19, 2 (Apr. 2016), 272–309. DOI:https://doi.org/10.1080/15213269.2015.1015740.

[57] Damşa, C.I. et al. 2010. Shared Epistemic Agency: An Empirical Study of an Emergent Construct. *Journal of the Learning Sciences*. 19, 2 (Apr. 2010), 143–186. DOI:https://doi.org/10.1080/10508401003708381.

[58] Davies, M. 2011. Concept mapping, mind mapping and argument mapping: what are the differences and do they matter? *Higher Education*. 62, (2011), 279–301.

[59] Dede, C. et al. 2017. EcoXPT: Designing for deeper learning through experimentation in an immersive virtual ecosystem. *Journal of Educational Technology \& Society*. 20, 4 (2017), 166–178.

[60] Denzin, N.K. 2009. The elephant in the living room: or extending the conversation about the politics of evidence. *Qualitative Research*. 9, 2 (Apr. 2009), 139–160. DOI:https://doi.org/10.1177/1468794108098034.

[61] Department for Business Innovation and Skills 2015. FELTAG Progress Report. February (2015), 10.

[62] Diaz, V. and Brown, M. 2010. Blended learning: A report on the ELI focus session (ELI Paper 2: 2010). *Boulder, CO: EDUCAUSE Learning Initiative.*

Retrieved from net. educause. edu/ir/library/pdf/ELI3023. pdf. (2010).

[63] Dinham, S. 2017. The Lack of an Evidence Base for Teaching and Learning: Fads, myths, legends, ideology and wishful thinking. *Professional Voice*. 11, 3 (2017), 17–25.

[64] Donnermann, M. et al. 2021. Social robots and gamification for technology supported learning: An empirical study on engagement and motivation. *Computers in Human Behavior*. 121, (Aug. 2021), 106792. DOI:https://doi.org/10.1016/j.chb.2021.106792.

[65] Doo, M.Y. et al. 2020. A Meta-Analysis of Scaffolding Effects in Online Learning in Higher Education. *The International Review of Research in Open and Distributed Learning*. 21, 3 (Mar. 2020). DOI:https://doi.org/10.19173/irrodl.v21i3.4638.

[66] Drever, E. 1995. *Using Semi-Structured Interviews in Small-Scale Research. A Teacher's Guide.* ERIC.

[67] Dushutina, E. V. 2021. Curriculum Development Approach – the Case of Computing Education. 151–170.

[68] Eckhaus, E. and others 2017. Towards tourism business change. *Revista de Management Comparat Internaţional*. 18, 3 (2017), 274–286.

[69] Edelson, D.C. et al. 1999. Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the learning sciences*. 8, 3–4 (1999), 391–450.

[70] Edwards, S. and Cooper, N. 2010. Mind mapping as a teaching resource. *Clinical Teacher*. 7, 4 (2010), 236–239. DOI:https://doi.org/10.1111/j.1743-498X.2010.00395.x.

[71] Ekman, I. 2013. On the desire to not kill your players: Rethinking sound in pervasive and mixed reality games. *Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play*. (2013), 142–149.

[72] Elizondo-Garcia, J. and Gallardo, K. 2020. Peer Feedback in Learner-Learner Interaction Practices. Mixed Methods Study on an xMOOC. *Electronic Journal of e-Learning*. 18, 2 (Feb. 2020). DOI:https://doi.org/10.34190/EJEL.20.18.2.002.

[73] English, W. 2000. Virtual reality and surgical education. *Journal of Surgical Simulation*. 5, 2–2 (2000). DOI:https://doi.org/10.1102/2051-7726.2018.a002.

[74] Expectations and goals for e-learning: 2009. *https://www.tonybates.ca/2009/06/18/expectations-and-goals-for-e-learning/*. Accessed: 2021-05-05.

[75] Faste, H. and Lin, H. 2012. The untapped promise of digital mind maps.

Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12 (New York, New York, USA, 2012), 1017.

[76] Felder, R.M. et al. 1988. Learning and teaching styles in engineering education. *Engineering education*. 78, 7 (1988), 674–681.

[77] Felder, R.M. 2002. Learning and teaching styles in engineering education. (2002).

[78] Fischer, F. et al. 2002. Fostering collaborative knowledge construction with visualization tools. *Learning and Instruction*. 12, 2 (Apr. 2002), 213–232. DOI:https://doi.org/10.1016/S0959-4752(01)00005-6.

[79] Flavián, C. et al. 2021. Impacts of technological embodiment through virtual reality on potential guests' emotions and engagement. *Journal of Hospitality Marketing & Management*. 30, 1 (Jan. 2021), 1–20. DOI:https://doi.org/10.1080/19368623.2020.1770146.

[80] Fleming, N. et al. 2006. Learning Styles Again: VARKing up the right tree! *Educ Dev*. 7, (2006).

[81] Forehand, M. 2010. Bloom ' s Taxonomy : Original and revised. *Emerging perspectives on learning, teaching, and technology*. (2010), 12. DOI:https://doi.org/1475074379.

[82] Fredricks, J.A. et al. 2004. School Engagement: Potential of the Concept, State of the Evidence. *Review of Educational Research*. 74, 1 (Mar. 2004), 59–109. DOI:https://doi.org/10.3102/00346543074001059.

[83] Furey, W. 2020. THE STUBBORN MYTH OF "LEARNING STYLES": State teacher-license prep materials peddle a debunked theory. *Education Next*. 20, (Dec. 2020), 8+.

[84] Gatewood, J. et al. 2022. From Singular Design to Differentiation: A History of Adaptive Systems. *TechTrends*. 66, 2 (2022), 131–133. DOI:https://doi.org/10.1007/s11528-022-00702-3.

[85] Gazely, A. and Pybus, L. 1997. Beyond the basic IT skills. *8th Annual CTI-AFM Conference, Newport* (1997).

[86] Georgiou, Y. and Kyza, E.A. 2018. Relations between student motivation, immersion and learning outcomes in location-based augmented reality settings. *Computers in Human Behavior*. 89, (Dec. 2018), 173–181. DOI:https://doi.org/10.1016/j.chb.2018.08.011.

[87] Gerig, N. et al. 2018. Missing depth cues in virtual reality limit performance and quality of three dimensional reaching movements. *PloS one*. 13, 1 (Jan. 2018), e0189275–e0189275. DOI:https://doi.org/10.1371/journal.pone.0189275.

[88] Gijlers, H. and de Jong, T. 2009. Sharing and Confronting Propositions in Collaborative Inquiry Learning. *Cognition and Instruction*. 27, 3 (Jul.

2009), 239–268. DOI:https://doi.org/10.1080/07370000903014352.

[89] Giraudeau, P. and Hachet, M. 2017. Towards a Mixed-Reality Interface for Mind-Mapping. *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces* (New York, NY, USA, Oct. 2017), 384–389.

[90] Golan, R. et al. 2002. Scaffolding the Task of Analyzing Animal Behavior with the Animal Landlord Software. *Annual Meeting of the American Educational Research Association*. (2002), 1–24.

[91] Gregory, M.S.J. and Lodge, J.M. 2015. Academic workload: the silent barrier to the implementation of technology-enhanced learning strategies in higher education. *Distance Education*. 36, 2 (2015), 210–230. DOI:https://doi.org/10.1080/01587919.2015.1055056.

[92] Grivokostopoulou, F. et al. 2016. An Innovative Educational Environment Based on Virtual Reality and Gamification for Learning Search Algorithms. *2016 IEEE Eighth International Conference on Technology for Education (T4E)* (Dec. 2016), 110–115.

[93] Guri-Rosenblit, S. and Gros, B. 2011. E-learning: Confusing terminology, research gaps and inherent challenges. *International Journal of E-Learning & Distance Education/Revue internationale du e-learning et la formation à distance*. 25, 1 (2011).

[94] Gurjar, N. 2020. Leveraging social networks for authentic learning in distance learning teacher education. *TechTrends*. 64, 4 (2020), 666–677.

[95] Haluck, R.S. 2000. Computers and Virtual Reality for Surgical Education in the 21st Century. *Archives of Surgery*. 135, 7 (2000), 786. DOI:https://doi.org/10.1001/archsurg.135.7.786.

[96] Hartt, M. et al. 2020. Game On: Exploring the Effectiveness of Game-based Learning. *Planning Practice & Research*. 35, 5 (Oct. 2020), 589–604. DOI:https://doi.org/10.1080/02697459.2020.1778859.

[97] Hase, S. and Kenyon, C. 2007. Heutagogy: A Child of Complexity Theory. *Complicity: An International Journal of Complexity and Education*. 4, 1 (Jul. 2007). DOI:https://doi.org/10.29173/cmplct8766.

[98] Heerwagen, J.H. et al. 2004. Collaborative knowledge work environments. *Building Research & Information*. 32, 6 (Nov. 2004), 510–528. DOI:https://doi.org/10.1080/09613210412331313025.

[99] Herlo, D. and Vlaicu, A. 2014. Paragogy. A New Theory in Educational Sciences. *Journal Plus Education*. X, 1 (2014), 35–41.

[100] Hettinger, L.J. et al. 2009. Vection and Simulator Sickness. *Military Psychology*. 5605, March 2012 (2009), 37–41. DOI:https://doi.org/10.1207/s15327876mp0203_4.

[101] Hidi, S. and Ann Renninger, K. 2006. The four-phase model of interest development. *Educational Psychologist*. 41, 2 (2006), 111–127. DOI:https://doi.org/10.1207/s15326985ep4102_4.

[102] Hilfert, T. and König, M. 2016. Low-cost virtual reality environment for engineering and construction. *Visualization in Engineering*. 4, 1 (2016), 2. DOI:https://doi.org/10.1186/s40327-015-0031-5.

[103] Hinckley, K. et al. 1994. A survey of design issues in spatial input. *Proceedings of the 7th annual ACM symposium on User interface software and technology - UIST '94* (New York, New York, USA, 1994), 213–222.

[104] Horn, M.S. et al. 2009. Comparing the use of tangible and graphical programming languages for informal science education. *Proceedings of the 27th international conference on Human factors in computing systems - CHI 09* (New York, New York, USA, 2009), 975.

[105] Huang, H.-M. et al. 2010. Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*. 55, 3 (Nov. 2010), 1171–1182. DOI:https://doi.org/10.1016/j.compedu.2010.05.014.

[106] Huang, H.-W. et al. 2012. The effectiveness of using procedural scaffoldings in a paper-plus-smartphone collaborative learning context. *Computers & Education*. 59, 2 (Sep. 2012), 250–259. DOI:https://doi.org/10.1016/j.compedu.2012.01.015.

[107] Hudson, S. et al. 2019. With or without you? Interaction and immersion in a virtual reality experience. *Journal of Business Research*. 100, (Jul. 2019), 459–468. DOI:https://doi.org/10.1016/j.jbusres.2018.10.062.

[108] Impey, C. et al. 2018. Videos for astronomy education and outreach. *Communicating Astronomy with the Public Journal*. 24, (2018), 32.

[109] Ioannidou, A. et al. 2009. AgentCubes: Incremental 3D end-user development. *Journal of Visual Languages & Computing*. 20, 4 (Aug. 2009), 236–251. DOI:https://doi.org/10.1016/j.jvlc.2009.04.001.

[110] ISAR, C. 2018. A Glance into Virtual Reality Development Using Unity. *Informatica Economica*. 22, 3/2018 (Sep. 2018), 14–22. DOI:https://doi.org/10.12948/issn14531305/22.3.2018.02.

[111] Israel, M.J. 2015. Effectiveness of Integrating MOOCs in Traditional Classrooms for Undergraduate Students. *The International Review of Research in Open and Distributed Learning*. 16, 5 (Sep. 2015). DOI:https://doi.org/10.19173/irrodl.v16i5.2222.

[112] Jackson, S.L. et al. 1994. Making Dynamic Modeling Accessible to Precollege Science Students. *Interactive Learning Environments*. 4, 3 (1994), 233–257. DOI:https://doi.org/10.1080/1049482940040305.

[113] Jamil, I. et al. 2017. Collaborating around Digital Tabletops. *ACM*

Transactions on Computer-Human Interaction. 24, 3 (May 2017), 1–30. DOI:https://doi.org/10.1145/3058551.

[114] Jamil, I. et al. 2011. The effects of interaction techniques on talk patterns in collaborative peer learning around interactive tables. *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11* (New York, New York, USA, 2011), 3043.

[115] Johanson, C. and Mandryk, R.L. 2016. Scaffolding player location awareness through audio cues in first-person shooters. *Conference on Human Factors in Computing Systems - Proceedings* (2016), 3450–3461.

[116] Johanson, C. and Mandryk, R.L. 2016. Scaffolding Player Location Awareness through Audio Cues in First-Person Shooters. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. (2016), 3450–3461. DOI:https://doi.org/10.1145/2858036.2858172.

[117] Jørgensen, K. 2017. Left in the dark: playing computer games with the sound turned off. *From Pac-Man to Pop Music*. K. Collins, ed. Routledge. 163–176.

[118] Kalelioğlu, F. and Gülbahar, Y. 2014. The effects of teaching programming via Scratch on problem solving skills: A discussion from learners' perspective. *Informatics in Education*. 13, 1 (2014), 33–50.

[119] Karim, H. 2014. Using VARK Approach for Assessing Preferred Learning Styles of First Year Medical Sciences Students: A Survey from Iran. *JOURNAL OF CLINICAL AND DIAGNOSTIC RESEARCH*. (2014). DOI:https://doi.org/10.7860/JCDR/2014/8089.4667.

[120] Karnik, A. et al. 2012. PiVOT. *Proceedings of the 25th annual ACM symposium on User interface software and technology - UIST '12* (New York, New York, USA, 2012), 271.

[121] Kaufmann H. Schmalstieg D. Wagner M. 2000. Construct3D: A Virtual Reality Application for Mathematics and Geometry Education. *Education and Information Technologies*. 5, 4 (2000), 14. DOI:https://doi.org/10.1023/A:1012049406877.

[122] Kim, H. and Hannafin, M.J. 2009. Web-enhanced case-based activity in teacher education: A case study. *Instructional Science*. 37, 2 (2009), 151–170.

[123] Kim, M.C. et al. 2007. Technology-enhanced inquiry tools in science education: An emerging pedagogical framework for classroom practice. *Science education*. 91, 6 (2007), 1010–1030.

[124] Kirkwood, A. and Price, L. 2014. Technology-enhanced learning and teaching in higher education: what is "enhanced" and how do we know? A critical literature review. *Learning, Media and Technology*. 39, 1 (2014), 6–36. DOI:https://doi.org/10.1080/17439884.2013.770404.

[125] Kirschner, P.A. et al. 2006. Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist*. 41, 2 (2006), 75–86. DOI:https://doi.org/10.1207/s15326985ep4102_1.

[126] Kirsh, D. 1994. On distinguishing epistemic from pragmatic action. *Cognitive Science*. 18, 4 (Dec. 1994), 513–549. DOI:https://doi.org/10.1016/0364-0213(94)90007-8.

[127] Knibbe, J. et al. 2018. The Dream is Collapsing. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (New York, New York, USA, 2018), 1–13.

[128] Kolasinski, E.M. 1995. Simulator Sickness in Virtual Environments. *United States Army Research Institute for the Behavioral and Social Sciences*.

[129] Kolb, A.Y. and Kolb, D.A. 2005. The Kolb Learning Style Inventory — Version 3 . 1 2005 Technical Specif cations. January 2005 (2005), 1–72.

[130] Kolb, D.A. 2014. *Experiential learning: Experience as the source of learning and development*. FT press.

[131] Kourtesis, P. and MacPherson, S.E. 2021. How immersive virtual reality methods may meet the criteria of the National Academy of Neuropsychology and American Academy of Clinical Neuropsychology: A software review of the Virtual Reality Everyday Assessment Lab (VR-EAL). *Computers in Human Behavior Reports*. 4, (Aug. 2021), 100151. DOI:https://doi.org/10.1016/j.chbr.2021.100151.

[132] Kwon, C. 2019. Verification of the possibility and effectiveness of experiential learning using HMD-based immersive VR technologies. *Virtual Reality*. 23, 1 (2019), 101–118.

[133] Kwon, S.Y. and Cifuentes, L. 2009. The comparative effect of individually-constructed vs. collaboratively-constructed computer-based concept maps. *Computers & Education*. 52, 2 (Feb. 2009), 365–375. DOI:https://doi.org/10.1016/j.compedu.2008.09.012.

[134] Lai, C. et al. 2015. March-and-Reach: A realistic ladder climbing technique. *2015 IEEE Symposium on 3D User Interfaces, 3DUI 2015 - Proceedings*. (2015), 15–18. DOI:https://doi.org/10.1109/3DUI.2015.7131719.

[135] Laister, J. et al. 2002. Social Aspects of Collaborative Learning in Virtual Learning Environments. (2002).

[136] Landa-Avila, I.C. and Cruz, M.-L. 2017. Engagement in a Virtual Reality Game with Gesture Hand Interface. An Empirical Evaluation of User Engagement Scale (UES). *DUXU 2017: Design, User Experience, and Usability: Designing Pleasurable Experiences* (2017), 414–427.

[137] Lanier, J. and Biocca, F. 1992. An Insider's View of the Future of Virtual

Reality. *Journal of Communication*. 42, 4 (Dec. 1992), 150–172. DOI:https://doi.org/10.1111/j.1460-2466.1992.tb00816.x.

[138] Laugwitz, B. et al. 2008. Construction and Evaluation of a User Experience Questionnaire. *Proceedings of the 4th Symposium of the Workgroup Human-Computer Interaction and Usability Engineering of the Austrian Computer* (2008), 63–76.

[139] LaViola, J.J. 2000. A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin*. 32, 1 (2000), 47–56. DOI:https://doi.org/10.1145/333329.333344.

[140] Lee, S.H. (Mark) et al. 2017. Assessing Google Cardboard virtual reality as a content delivery system in business classrooms. *Journal of Education for Business*. 92, 4 (May 2017), 153–160. DOI:https://doi.org/10.1080/08832323.2017.1308308.

[141] Li, J. 2010. Learning vocabulary via computer-assisted scaffolding for text processing. *Computer Assisted Language Learning*. 23, 3 (Jul. 2010), 253–275. DOI:https://doi.org/10.1080/09588221.2010.483678.

[142] LI, Y. et al. 2019. Gesture interaction in virtual reality. *Virtual Reality & Intelligent Hardware*. 1, 1 (Feb. 2019), 84–112. DOI:https://doi.org/10.3724/SP.J.2096-5796.2018.0006.

[143] LightBot: 2017. .

[144] Lin, H. and Faste, H. 2011. Digital Mind Mapping : Innovations for Real-time Collaborative Thinking. *CHI'11 Extended Abstracts on Human Factors in Computing Systems*. (2011), 2142–2137. DOI:https://doi.org/10.1145/1979742.1979910.

[145] Linnenbrink-Garcia, L. et al. 2010. Measuring situational interest in academic domains. *Educational and Psychological Measurement*. 70, 4 (2010), 647–671. DOI:https://doi.org/10.1177/0013164409355699.

[146] Lissermann, R. et al. 2014. Permulin : Mixed-Focus Collaboration on Multi-View Tabletops. (2014).

[147] Liton, H.A. 2015. Examining students' perception efficacy of using technology in teaching English. *International Journal of Education and Information Technology*. 1, 1 (2015), 11–19.

[148] Looser, J. et al. 2007. An evaluation of virtual lenses for object selection in augmented reality. *Proceedings - GRAPHITE 2007, 5th International Conference on Computer Graphics and Interactive Techniques in Australasia and Southeast Asia*. 1, 212 (2007), 203–210. DOI:https://doi.org/10.1145/1321261.1321297.

[149] Lou, Y. et al. 2001. Small Group and Individual Learning with Technology: A Meta-Analysis. *Review of Educational Research*. 71, 3 (Sep. 2001), 449–

521. DOI:https://doi.org/10.3102/00346543071003449.

[150] Lou, Y. 2004. Understanding Process and Affective Factors in Small Group versus Individual Learning with Technology. *Journal of Educational Computing Research*. 31, 4 (Dec. 2004), 337–369. DOI:https://doi.org/10.2190/XF5A-T29G-X170-7950.

[151] Lu, J. and Zhang, Z. 2013. Scaffolding argumentation in intact class: Integrating technology and pedagogy. *Computers and Education*. 69, (2013), 189–198. DOI:https://doi.org/10.1016/j.compedu.2013.07.021.

[152] Maloney, J. et al. 2010. The scratch programming language and environment. *ACM Transactions on Computing Education*. 10, 4 (2010), 1–15. DOI:https://doi.org/10.1145/1868358.1868363.

[153] McCracken, M. et al. 2001. A multi-national, multi-institutional study of assessment of programming skills of first-year CS students. *Working group reports from ITiCSE on Innovation and technology in computer science education* (New York, NY, USA, Dec. 2001), 125–180.

[154] McLaughlin, J.E. et al. 2014. The Flipped Classroom. *Academic Medicine*. 89, 2 (Feb. 2014), 236–243. DOI:https://doi.org/10.1097/ACM.0000000000000086.

[155] McMahan, R.P. et al. 2010. Evaluating natural interaction techniques in video games. *3DUI 2010 - IEEE Symposium on 3D User Interfaces 2010, Proceedings*. (2010), 11–14. DOI:https://doi.org/10.1109/3DUI.2010.5444727.

[156] McMahan, R.P. et al. 2017. *Virtual, Augmented and Mixed Reality*. Springer International Publishing.

[157] Means, B. et al. 2009. Evaluation of Evidence-Based Practices in Online Learning. *Structure*. (2009), 66.

[158] Meek, S.E.M. et al. 2017. Is peer review an appropriate form of assessment in a MOOC? Student participation and performance in formative peer review. *Assessment & Evaluation in Higher Education*. 42, 6 (Aug. 2017), 1000–1013. DOI:https://doi.org/10.1080/02602938.2016.1221052.

[159] Melcer, E.F. and Isbister, K. 2018. Bots & (Main)Frames: Exploring the Impact of Tangible Blocks and Collaborative Play in an Educational Programming. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (New York, New York, USA, 2018), 1–14.

[160] Meltzoff, A.N. et al. 2009. Foundations for a New Science of Learning. *Science*. 325, 5938 (Jul. 2009), 284–288. DOI:https://doi.org/10.1126/science.1175626.

[161] Mento, A.J. et al. 1999. Mind mapping in executive education: Applications and outcomes. *Journal of Management Development*. 18, 4 (1999), 390–416. DOI:https://doi.org/10.1108/02621719910265577.

[162] Merchant, Z. et al. 2014. Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*. 70, (Jan. 2014), 29–40. DOI:https://doi.org/10.1016/j.compedu.2013.07.033.

[163] Mikropoulos, T.A. and Natsis, A. 2011. Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & Education*. 56, 3 (Apr. 2011), 769–780. DOI:https://doi.org/10.1016/j.compedu.2010.10.020.

[164] Miyasugi, M. et al. 2017. Implementation and evaluation of multi-user mind map authoring system using virtual reality and hand gestures. *2017 IEEE 6th Global Conference on Consumer Electronics, GCCE 2017*. 2017-Janua, Gcce (2017), 1–5. DOI:https://doi.org/10.1109/GCCE.2017.8229432.

[165] Moehring, M. and Froehlich, B. 2005. Pseudo-physical Interaction with a Virtual Car Interior in Immersive Environments. *Proceedings of the 11th Eurographics Conference on Virtual Environments* (Aire-la-Ville, Switzerland, Switzerland, 2005), 181–189.

[166] Möllers, M. and Jan, B. 2011. TaPS widgets: Interacting with tangible private spaces. *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces, ITS'11*. (2011), 75–78. DOI:https://doi.org/10.1145/2076354.2076369.

[167] Montgomery, S. and Fogler, H.S. 1996. A classification scheme for interactive computer-aided instructional software. *submitted for publication*. (1996).

[168] Morra, S. et al. 2012. *Cognitive Development*. Psychology Press.

[169] Mumtaz, S. 2000. Factors affecting teachers' use of information and communications technology: a review of the literature. *Journal of Information Technology for Teacher Education*. 9, 3 (Oct. 2000), 319–342. DOI:https://doi.org/10.1080/14759390000200096.

[170] Muntean, C.I. 2011. Raising engagement in e-learning through gamification. *Proc. 6th international conference on virtual learning ICVL* (2011), 323–329.

[171] Nabiyouni, M. et al. 2015. Comparing the Performance of Natural , Semi-Natural , and Non-Natural. *IEEE Virutal Reality 2015*. (2015), 243–244. DOI:https://doi.org/doi:10.1109/3dui.2015.7131717.

[172] Nancekivell, S.E. et al. 2021. A Slippery Myth: How Learning Style Beliefs Shape Reasoning about Multimodal Instruction and Related Scientific Evidence. *Cognitive Science*. 45, 10 (Oct. 2021). DOI:https://doi.org/10.1111/cogs.13047.

[173] Nandagopal R, R.R. 2015. A Study on the Influence of Senses and the Effectiveness of Sensory Branding. *Journal of Psychiatry*. 18, 2 (2015). DOI:https://doi.org/10.4172/Psychiatry.1000236.

[174] National curriculum in England: computing programmes of study: 2013. *https://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study/national-curriculum-in-england-computing-programmes-of-study*.

[175] O'Brien, H.L. et al. 2018. A practical approach to measuring user engagement with the refined user engagement scale (UES) and new UES short form. *International Journal of Human-Computer Studies*. 112, (Apr. 2018), 28–39. DOI:https://doi.org/10.1016/j.ijhcs.2018.01.004.

[176] O'Brien, H.L. and Toms, E.G. 2008. What is user engagement? A conceptual framework for defining user engagement with technology. *Journal of the American Society for Information Science and Technology*. 59, 6 (Apr. 2008), 938–955. DOI:https://doi.org/10.1002/asi.20801.

[177] O'Connor, E.A. and Domingo, J. 2017. A Practical Guide, With Theoretical Underpinnings, for Creating Effective Virtual Reality Learning Environments. *Journal of Educational Technology Systems*. 45, 3 (2017), 343–364. DOI:https://doi.org/10.1177/0047239516673361.

[178] O'Neil, H.F. et al. 2005. Classification of learning outcomes: evidence from the computer games literature. *The Curriculum Journal*. 16, 4 (Dec. 2005), 455–474. DOI:https://doi.org/10.1080/09585170500384529.

[179] Oculus Rift: Step Into the Game: 2012. *https://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game*. Accessed: 2022-08-02.

[180] Okada, T. 1997. Collaborative discovery in a scientific domain. *Cognitive Science*. 21, 2 (Jun. 1997), 109–146. DOI:https://doi.org/10.1016/S0364-0213(99)80020-2.

[181] Olaniran, B. 2008. Culture and Communication Challenges in Virtual Workspaces. *Virtual Technologies*. IGI Global. 1014–1027.

[182] Ortega, F.R. et al. 2017. Towards a 3D Virtual Programming Language to increase the number of women in computer science education. *2017 IEEE Virtual Reality Workshop on K-12 Embodied Learning through Virtual & Augmented Reality (KELVAR)* (Mar. 2017), 1–6.

[183] Oxman, S. et al. 2014. White paper: Adaptive learning systems. *Integrated Education Solutions*. (2014), 6–7.

[184] Parker, J.R. and Heerema, J. 2008. Audio Interaction in Computer Mediated Games. *International Journal of Computer Games Technology*. 2008, (2008), 1–8. DOI:https://doi.org/10.1155/2008/178923.

[185] Parmar, D. et al. 2016. Programming moves: Design and evaluation of applying embodied interaction in virtual environments to enhance computational thinking in middle school students. *2016 IEEE Virtual Reality (VR)* (2016), 131–140.

[186] Parsons, T.D. et al. 2019. A Comparison of Virtual Reality Classroom Continuous Performance Tests to Traditional Continuous Performance Tests in Delineating ADHD: a Meta-Analysis. *Neuropsychology Review*. 29, 3 (Sep. 2019), 338–356. DOI:https://doi.org/10.1007/s11065-019-09407-6.

[187] Partovi, T. and Razavi, M.R. 2019. The effect of game-based learning on academic achievement motivation of elementary school students. *Learning and Motivation*. 68, (Nov. 2019), 101592. DOI:https://doi.org/10.1016/j.lmot.2019.101592.

[188] Paterson, C. et al. 2020. What are students' needs and preferences for academic feedback in higher education? A systematic review. *Nurse Education Today*. 85, (Feb. 2020), 104236. DOI:https://doi.org/10.1016/j.nedt.2019.104236.

[189] Patton, M.Q. 2015. *Qualitative evaluation and research methods*. SAGE Publications, inc.

[190] Pedaste, M. et al. 2015. Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*. 14, (2015), 47–61. DOI:https://doi.org/10.1016/j.edurev.2015.02.003.

[191] Pellas, N. and Vosinakis, S. 2018. The effect of simulation games on learning computer programming: A comparative study on high school students' learning performance by assessing computational problem-solving strategies. *Education and Information Technologies*. 23, 6 (Nov. 2018), 2423–2452. DOI:https://doi.org/10.1007/s10639-018-9724-4.

[192] Petrykowski, M. et al. 2019. Digital Collaboration with a Whiteboard in Virtual Reality. 962–981.

[193] Petty, G. 2016. *Teaching today: A practical guide*. Oxford University Press-Children.

[194] Piaget, J. 1966. The Psychology of Intelligence and Education. *Childhood Education*. 42, 9 (May 1966), 528–528. DOI:https://doi.org/10.1080/00094056.1966.10727991.

[195] Piaget, J. and Duckworth, E. 1970. Genetic Epistemology. *American Behavioral Scientist*. 13, 3 (Jan. 1970), 459–480. DOI:https://doi.org/10.1177/000276427001300320.

[196] Piumsomboon, T. et al. 2018. Mini-Me. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (New York, New York, USA, 2018), 1–13.

[197] Plass, J.L. et al. 2013. The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. *Journal of Educational Psychology*. 105, 4 (2013), 1050–1066. DOI:https://doi.org/10.1037/a0032688.

[198] Psotka, J. 1995. Immersive training systems: Virtual reality and education

and training. *Instructional Science*. 23, 5–6 (Nov. 1995), 405–431. DOI:https://doi.org/10.1007/BF00896880.

[199] Radianti, J. et al. 2020. A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*. 147, (Apr. 2020), 103778. DOI:https://doi.org/10.1016/j.compedu.2019.103778.

[200] Research Ethics: *https://www.lancaster.ac.uk/sci-tech/research/ethics/#tips-for-a-good-application-556100-9*.

[201] Resnick, M. et al. 2009. Scratch. *Communications of the ACM*. 52, 11 (Nov. 2009), 60–67. DOI:https://doi.org/10.1145/1592761.1592779.

[202] Rivky, M. et al. 2022. Utilization of Virtual Reality Chat as A Means of Learning Communication in The Field of Education. *ASEAN Journal of Community Service and Education*. 1, 1 (2022), 23–30.

[203] Rizzo, A.A. et al. 2002. The Virtual Classroom: A Virtual Reality Environment for the Assessment and Rehabilitation of Attention Deficits. *CyberPsychology & Behavior*. 3, 3 (2002), 483–499. DOI:https://doi.org/10.1089/10949310050078940.

[204] Roberts, F.D. et al. 2007. Factors influencing accounting faculty members' decision to adopt technology in the classroom. *College Student Journal*. 41, 2 (2007), 423–436.

[205] Robotc: A C programming language for robotic: 2019. *https://www.robotc.net/*. Accessed: 2020-08-03.

[206] Rogers, K. 2017. Exploring the role of audio in games. *CHI PLAY 2017 Extended Abstracts - Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play*. (2017), 727–731. DOI:https://doi.org/10.1145/3130859.3133227.

[207] Roth, W.-M. and Jornet, A. 2017. Understanding educational psychology. *A Late Vygotskian, Spinozist Approach. Springer International Publishing Switzerland,*. (2017).

[208] Roth, W.-M. and Roychoudhury, A. 1993. The development of science process skills in authentic contexts. *Journal of Research in Science Teaching*. 30, 2 (Feb. 1993), 127–152. DOI:https://doi.org/10.1002/tea.3660300203.

[209] Ruthenbeck, G.S. and Reynolds, K.J. 2015. Virtual reality for medical training: the state-of-the-art. *Journal of Simulation*. 9, 1 (Feb. 2015), 16–26. DOI:https://doi.org/10.1057/jos.2014.14.

[210] Ryall, K. et al. 2004. Exploring the effects of group size and table size on interactions with tabletop shared-display groupware. *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW*. (2004), 284–293. DOI:https://doi.org/10.1145/1031607.1031654.

[211] Ryve, A. 2004. Can collaborative concept mapping create mathematically productive discourses? *Educational Studies in Mathematics*. 56, 3 (2004), 157–177. DOI:https://doi.org/10.1023/B:EDUC.0000040395.17555.c2.

[212] Sampayo-Vargas, S. et al. 2013. The effectiveness of adaptive difficulty adjustments on students' motivation and learning in an educational computer game. *Computers & Education*. 69, (Nov. 2013), 452–462. DOI:https://doi.org/10.1016/j.compedu.2013.07.004.

[213] San Chee, Y. 2001. Virtual reality in education: Rooting learning in experience. *International Symposium on Virtual Education* (2001).

[214] Sandoval, W.A. and Reiser, B.J. 2004. Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*. 88, 3 (2004), 345–372. DOI:https://doi.org/10.1002/sce.10130.

[215] Sandoval, W.A. and Reiser, B.J. 2004. Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*. 88, 3 (May 2004), 345–372. DOI:https://doi.org/10.1002/sce.10130.

[216] Sangster, A. 1992. Computer-based instruction in accounting education. *Accounting Education*. 1, 1 (Mar. 1992), 13–32. DOI:https://doi.org/10.1080/09639289200000003.

[217] Santoso, H.B. et al. 2016. Measuring user experience of the student-centered E-learning environment. *Journal of Educators Online*. 13, 1 (2016), 1–79.

[218] Santrock, J. 2007. *A Topical Approach to Lifespan Development, 9e*.

[219] Saunier, J. et al. 2016. Designing adaptable virtual reality learning environments. *Proceedings of the 2016 Virtual Reality International Conference* (New York, NY, USA, Mar. 2016), 1–4.

[220] Schiefele, U. 2009. Interest and Learning From Text. *Scientific Studies of Reading*. 8438, 1999 (2009), 37–41. DOI:https://doi.org/10.1207/s1532799xssr0303_4.

[221] Schraw, G. and Lehman, S. 2014. Situational Interest : A Review of the Literature and Directions for Future Research Author (s). *Review, Educational Psychology*. 13, 1 (2014), 23–52. DOI:https://doi.org/10.1023/A:1009004801455.

[222] Schrepp, M. et al. 2017. Construction of a Benchmark for the User Experience Questionnaire (UEQ). *International Journal of Interactive Multimedia and Artificial Intelligence*. 4, 4 (2017), 40. DOI:https://doi.org/10.9781/ijimai.2017.445.

[223] Scott, S.D. et al. 2004. Territoriality in collaborative tabletop workspaces. *Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW*. (2004), 294–303. DOI:https://doi.org/10.1145/1031607.1031655.

[224] Seidman, I. 2006. *Interviewing as qualitative research: A guide for researchers in education and the social sciences*. Teachers college press.

[225] Senik, R. and Broad, M. 2011. Information technology skills development for accounting graduates: Intervening conditions. *International Education Studies*. 4, 2 (2011), 105–110.

[226] Serrano, D.R. et al. 2019. Technology-enhanced learning in higher education: How to enhance student engagement through blended learning. *European Journal of Education*. 54, 2 (2019), 273–286. DOI:https://doi.org/10.1111/ejed.12330.

[227] Shao, G. et al. 2021. Exploring potential roles of academic libraries in undergraduate data science education curriculum development. *The Journal of Academic Librarianship*. 47, 2 (Mar. 2021), 102320. DOI:https://doi.org/10.1016/j.acalib.2021.102320.

[228] Shepard, L.A. 2005. Linking formative assessment to scaffolding. *Educational leadership*. 63, 3 (2005), 66–70.

[229] Sherman, W.R. and Craig, A.B. 2003. Understanding virtual reality—Interface, application, and design. MIT Press.

[230] Shih, T.K. et al. 2004. A VR-based shared web system for distance education. *Interactive Technology and Smart Education*. 1, 4 (Nov. 2004), 225–238. DOI:https://doi.org/10.1108/17415650480000025.

[231] Shin, T.S. et al. 2017. Effects of peer and instructor rationales on online students' motivation and achievement. *International Journal of Educational Research*. 82, (2017), 184–199. DOI:https://doi.org/10.1016/j.ijer.2017.02.001.

[232] Shulman, L.S. 2005. Signature Pedagogies in the Professions. *Daedalus*. 134, 3 (Oct. 2005), 52–59.

[233] Sidenmark, L. et al. 2020. BimodalGaze: Seamlessly Refined Pointing with Gaze and Filtered Gestural Head Movement. *ACM Symposium on Eye Tracking Research and Applications* (New York, NY, USA, Jun. 2020), 1–9.

[234] Sidenmark, L. et al. 2020. Outline Pursuits: Gaze-assisted Selection of Occluded Objects in Virtual Reality. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, Apr. 2020), 1–13.

[235] Sims, R. et al. 2021. Logibot: Investigating Engagement and Development of Computational Thinking Through Virtual Reality. *2021 7th International Conference of the Immersive Learning Research Network (iLRN)* (May 2021), 1–5.

[236] Sims, R. et al. 2022. Step Into My Mind Palace: Exploration of a Collaborative Paragogy Tool in VR. *2022 8th International Conference of*

the Immersive Learning Research Network (iLRN) (May 2022), 1–8.

[237] Sims, R. 2019. VERITAS.

[238] Sims, R. and Karnik, A. 2021. VERITAS: Mind-Mapping in Virtual Reality. *2021 7th International Conference of the Immersive Learning Research Network (iLRN)* (May 2021), 1–8.

[239] Sinclair, J. and Aho, A.M. 2018. Experts on super innovators: understanding staff adoption of learning management systems. *Higher Education Research and Development*.

[240] Slavova, Y. and Mu, M. 2018. A Comparative Study of the Learning Outcomes and Experience of VR in Education. *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (2018), 685–686.

[241] Smith, P.C. and Hamilton, B.K. 2015. The Effects of Virtual Reality Simulation as a Teaching Strategy for Skills Preparation in Nursing Students. *Clinical Simulation in Nursing*. 11, 1 (Jan. 2015), 52–58. DOI:https://doi.org/10.1016/j.ecns.2014.10.001.

[242] Sotiriou, S. and Bogner, F.X. 2008. Visualizing the Invisible: Augmented Reality as an Innovative Science Education Scheme. *Advanced Science Letters*. 1, 1 (2008), 114–122. DOI:https://doi.org/10.1166/asl.2008.012.

[243] Speicher, M. et al. 2018. Selection-based Text Entry in Virtual Reality. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18* (New York, New York, USA, 2018), 1–13.

[244] Stice, J.E. 1987. Using Kolb's Learning Cycle to Improve Student Learning. *Engineering education*. 77, 5 (1987), 291–296.

[245] Stoffregen, T; Smart, L. 1997. Postural instability precedes motion sickness. *Brain Research Bulletin*. 47, 5 (1997), 437–448.

[246] Stolee, K.T. and Fristoe, T. 2011. Expressing computer science concepts through Kodu game lab. *Proceedings of the 42nd ACM technical symposium on Computer science education* (New York, NY, USA, Mar. 2011), 99–104.

[247] Su, J.-M. 2015. A self-regulated learning tutor to adaptively scaffold the personalized learning: A study on learning outcome for grade 8 Mathematics. *2015 8th International Conference on Ubi-Media Computing (UMEDIA)* (Aug. 2015), 376–380.

[248] Suárez, Á. et al. 2018. A review of the types of mobile activities in mobile inquiry-based learning. *Computers & Education*. 118, (Mar. 2018), 38–55. DOI:https://doi.org/10.1016/j.compedu.2017.11.004.

[249] Sutherland, I. 1965. The ultimate display. (1965).

[250] Suthers, D.D. and Hundhausen, C.D. 2003. An Experimental Study of the

Effects of Representational Guidance on Collaborative Learning Processes. *Journal of the Learning Sciences*. 12, 2 (Apr. 2003), 183–218. DOI:https://doi.org/10.1207/S15327809JLS1202_2.

[251] Sutton, J. and Austin, Z. 2015. Qualitative Research: Data Collection, Analysis, and Management. *The Canadian Journal of Hospital Pharmacy*. 68, 3 (Jun. 2015). DOI:https://doi.org/10.4212/cjhp.v68i3.1456.

[252] Tang, A. et al. 2006. Collaborative coupling over tabletop displays. *Conference on Human Factors in Computing Systems - Proceedings*. 2, (2006), 1181–1190. DOI:https://doi.org/10.1145/1124772.1124950.

[253] Tatale, S. et al. 2019. A review on Virtual Reality for educating students with learning disabilities. *2019 5th International Conference On Computing, Communication, Control And Automation (ICCUBEA)* (Sep. 2019), 1–6.

[254] Teasley, S.D. 1997. Talking about reasoning: How important is the peer in peer collaboration? *Discourse, tools and reasoning*. Springer. 361–384.

[255] Teather, R.J. and Stuerzlinger, W. 2013. Pointing at 3d target projections with one-eyed and stereo cursors. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, Apr. 2013), 159–168.

[256] Tergan, S. 2005. Digital Concept Maps for Managing Knowledge and Information. *Conference: Knowledge and Information Visualization, Searching for Synergies*. 185–204.

[257] Toth, E.E. et al. 2002. “Mapping to know”: The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education*. 86, 2 (Mar. 2002), 264–286. DOI:https://doi.org/10.1002/sce.10004.

[258] Tussyadiah, I.P. et al. 2018. Embodiment of Wearable Augmented Reality Technology in Tourism Experiences. *Journal of Travel Research*. 57, 5 (May 2018), 597–611. DOI:https://doi.org/10.1177/0047287517709090.

[259] User Experience Questionnaire (UEQ): 2018. *https://www.ueq-online.org*. Accessed: 2020-09-24.

[260] Vermunt, J.D. 1994. Inventory of learning styles (ILS). *Tilburg, The Netherlands: Tilburg University, Department of Educational Psychology*. (1994).

[261] Vinson, N.G. 1999. Design guidelines for landmarks to support navigation in virtual environments. *Proceedings of the SIGCHI conference on Human factors in computing systems the CHI is the limit - CHI '99* (New York, New York, USA, 1999), 278–285.

[262] VR-AR-Corp 2018. Mind Map VR. VR-AR Corp.

[263] de Vries, E. et al. 2002. Computer-Mediated Epistemic Dialogue:

Explanation and Argumentation as Vehicles for Understanding Scientific Notions. *Journal of the Learning Sciences*. 11, 1 (Jan. 2002), 63–103. DOI:https://doi.org/10.1207/S15327809JLS1101_3.

[264] Vrtoolkit.readme.io 2021. VRTK - Virtual Reality Toolkit.

[265] Vygotsky, L.S. and Cole, M. 1978. *Mind in society: Development of higher psychological processes*. Harvard university press.

[266] Wade, S.E. et al. 1993. Seduction of the Strategic Reader: Effects of Interest on Strategies and Recall. *Reading Research Quarterly*. 28, 2 (Apr. 1993), 92. DOI:https://doi.org/10.2307/747885.

[267] Wang, C. et al. 2022. Integrating computational thinking in STEM education: A literature review. *International Journal of Science and Mathematics Education*. 20, 8 (2022), 1949–1972.

[268] Weaver, D. et al. 2008. Academic and student use of a learning management system: Implications for quality. *Australasian Journal of Educational Technology*. 24, 1 (Jan. 2008). DOI:https://doi.org/10.14742/ajet.1228.

[269] Weinberger, A. et al. 2007. Knowledge convergence in collaborative learning: Concepts and assessment. *Learning and Instruction*. 17, 4 (Aug. 2007), 416–426. DOI:https://doi.org/10.1016/j.learninstruc.2007.03.007.

[270] Weintrop, D. et al. 2018. Evaluating CoBlox: A comparative study of robotics programming environments for adult novices. *Conference on Human Factors in Computing Systems - Proceedings*. 2018-April, (2018), 2018. DOI:https://doi.org/10.1145/3173574.3173940.

[271] Wenning, C.J. 2005. Whiteboarding and Socratic dialogues: Questions and answers. *Journal of Physics Teacher Education Online*. 3, 1 (2005), 3–10.

[272] Williams-Bell, F.M. et al. 2015. Using Serious Games and Virtual Simulation for Training in the Fire Service: A Review. *Fire Technology*. 51, 3 (May 2015), 553–584. DOI:https://doi.org/10.1007/s10694-014-0398-1.

[273] Williamson, K.M. and Muckle, J. 2018. Students' Perception of Technology Use in Nursing Education. *CIN: Computers, Informatics, Nursing*. 36, 2 (Feb. 2018), 70–76. DOI:https://doi.org/10.1097/CIN.0000000000000396.

[274] Wilson, J.D. et al. 1993. The benefits of collaboration for student programmers. *ACM SIGCSE Bulletin*. 25, 1 (1993), 160–164.

[275] Wing, J.M. 2006. Computational thinking. *Communications of the ACM*. 49, 3 (Mar. 2006), 33–35. DOI:https://doi.org/10.1145/1118178.1118215.

[276] Witherspoon, E.B. et al. 2017. Developing Computational Thinking through a Virtual Robotics Programming Curriculum. *ACM Transactions on Computing Education*. 18, 1 (Dec. 2017), 1–20. DOI:https://doi.org/10.1145/3104982.

[277] Wood, D. et al. 1976. THE ROLE OF TUTORING IN PROBLEM SOLVING. *Journal of Child Psychology and Psychiatry*. 17, 2 (Apr. 1976), 89–100. DOI:https://doi.org/10.1111/j.1469-7610.1976.tb00381.x.

[278] Wu, C.-H. et al. 2017. An Adaptive e-Learning System for Enhancing Learning Performance: Based on Dynamic Scaffolding Theory. *EURASIA Journal of Mathematics, Science and Technology Education*. 14, 3 (Dec. 2017). DOI:https://doi.org/10.12973/ejmste/81061.

[279] Yan, H. et al. 2011. Research on Augmented Reality Display Method of Scientific Exhibits. *Transactions on Edutainment V*. Z. Pan et al., eds. Springer Berlin Heidelberg. 259–269.

[280] Yang, Y. et al. 2018. Maps and Globes in Virtual Reality. *Computer Graphics Forum*. 37, 3 (2018), 427–438. DOI:https://doi.org/10.1111/cgf.13431.

[281] Yehdeya, E.F. et al. 2023. Analisis User Interface (UI) Dan User Experience (UX) Sudut Elevasi Pemukul Gamelan Metaverse Virtual Reality Menggunakan User Centered Design (UCD). *JIKO (Jurnal Informatika dan Komputer)*. 7, 1 (Feb. 2023), 137. DOI:https://doi.org/10.26798/jiko.v7i1.757.

[282] Ying, L. et al. 2014. The Effect of Mind Mapping on Teaching and Learning: A Meta-Analysis. *Standard Journal of Education and Essay*. 2, 1 (2014), 17–31.

[283] Young, C.O. 2014. Employing Virtual Reality Technology at Trial: New Issues Posed by Rapid Technological Advances and Their Effects on Jurors' Search for the Truth. *Tex. L. Rev.* 93, (2014), 257.

[284] Yu, D. et al. 2020. Fully-Occluded Target Selection in Virtual Reality. *IEEE Transactions on Visualization and Computer Graphics*. 26, 12 (Dec. 2020), 3402–3413. DOI:https://doi.org/10.1109/TVCG.2020.3023606.

[285] Zarei, E. et al. 2014. The level at which accounting professors use information technology at universities. *Journal of Accounting Research*. 4, 2 (2014), 159–174.

[286] Zhai, S. et al. 1994. The "Silk Cursor." *Proceedings of the SIGCHI conference on Human factors in computing systems celebrating interdependence - CHI '94* (New York, New York, USA, 1994), 459–464.

[287] Zhang, Z. and Linn, M. 2008. Using drawings to support learning from dynamic visualizations. (2008).

[288] Zimmaro, D.M. and Cawley, J.M. 1998. Concept map module. *Schreyer institute for innovation in learning, The Pennsylvania State University*. (1998).

[289] Zipp, G.P. et al. 2009. Mind Maps: Useful Schematic Tool For Organizing And Integrating Concepts Of Complex Patient Care In The Clinic And

Classroom. *Journal of College Teaching & Learning (TLC)*. 6, 2 (2009), 59–68. DOI:https://doi.org/10.19030/tlc.v6i2.1173.