Assessing Understanding Gained of Nottingham Caves through Projected Augmented Relief Model (PARM)

Submitted in partial fulfilment of the requirements for the degree of Master of Research in Geospatial Data Science as part of the CDT in Geospatial Systems

Ayisha Dubi - 20605094

Associate Professor Gary Priestnall

School of Engineering
University of Nottingham

Declaration

I hereby declare that this dissertation is all my own work, except as indicated in thetext.

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Abstract

This dissertation examines the effectiveness of Projected Augmented Relief Models (PARM) in improving the educational understanding of geographical and historical contexts, specifically focusing on the Nottingham caves. The research targets two distinct educational demographics: school children and postgraduate students. By integrating digital and physical modeling aspects, PARM aims to enhance spatial comprehension and facilitate interactive learning (Priestnall et al., 2012). Utilizing a mixed-methods approach, including surveys, observational studies, interviews, and user feedback, this study evaluates PARM's impact compared to traditional 2D maps (Manduca & Mogk, 2006; Wiltshier & Edwards, 2014). Quantitative assessments involve pre-and post-tests to measure knowledge gains (Chen et al., 2018; Ştefan, 2012), while qualitative feedback highlights user engagement and pedagogical effectiveness.

The results demonstrate that PARM significantly enhances excitement and informational retention compared to traditional methods, particularly among school-aged participants. A notable correlation between increased excitement and enhanced understanding suggests that PARM's engaging visualizations effectively promote deeper learning. Feedback from participants underscores the model's ability to simplify complex information, making it accessible and engaging. Substantial improvements in test scores further corroborate PARM's effectiveness as an educational tool.

The study concludes that PARM not only significantly enriches learning experiences but also has the potential to be integrated with advanced technologies like virtual reality further to enhance educational outcomes (Khaitov, 2019). The findings advocate for broader application and continuous development of PARM technologies across various academic levels and settings to maximize its educational benefits and adaptability.

Keywords: Projected Augmented Relief Model (PARM), Educational technology, Spatial understanding, Geographical visualization, Mixed-methods approach, Nottingham Caves

Abbreviations

1. **2D** – Printed Paper Maps
2. **3D model** – Projected Augmented Relief Model (PARM)
3. **AR -** Augmented Reality
4. **CNC** - Computer Numerically Controlled
5. **GPU -** Graphics Processing Unit
6. **K-12 -** Kindergarten through 12th grade
7. **KS3 -** Key Stage 3
8. **PARM** - Projected Augmented Relief Model
9. **TV** – Television- PowerPoint
10. **VR** - Virtual Reality

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1. Introduction

The Projected Augmented Relief Model (PARM) provides an immersive and interactive way to engage with spatial data, offering a tactile representation of geographic features to help users orient within landscapes (Sprinks, J. et al., 2020). The Projected Augmented Relief Model (PARM) **(Figure 1)** provides a versatile three-dimensional platform that can be adapted for a variety of uses. With the simple push of a button, it enables the examination of different scenarios, and supporting activities such as research, data analysis, and local government planning (www.nottingham.ac.uk, n.d.).

Figure 1: The Large Nottingham Model displayed at the 'City as Lab' on Castle Meadow Campus

The use of PARM has been integral to initiatives led by Digital Nottingham, enhancing community engagement and urban development through innovative 3D technologies (www.nottingham.ac.uk, n.d.; Leeuwen, v, J. et al., 2018). One notable implementation of this technology was by Dr. Priestnall, who created the 'Grandest Views' exhibition at Keswick Museum in 2015, showcased historical and modern landscape modeling techniques and developed a specialized PARM for Keswick School **(Figure 8)** (www.nottingham.ac.uk, n.d.).

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Despite its applications, there is limited research on the understanding gained from the use of PARM, particularly for the Large Nottingham model launched in March 2024. This study aims to fill this gap by collaborating with professionals to develop educational materials for Nottingham caves and evaluating the effectiveness of PARM displays in enhancing understanding among school groups and postgraduate students (Sommerauer, P. and Müller, O., 2014). This research will provide empirical evidence on the educational gains offered by PARM displays, supporting the use of interactive geographic visualizations in educational contexts.

Recent studies have demonstrated the positive impact of augmented reality and interactive visualization on student motivation and academic performance in engineering and other fields (Fonseca, D. et al., 2014; Contero, M. et al., 2012). These findings suggest that the integration of PARM technology in the context of the Nottingham Caves could similarly enhance students' understanding and engagement.

1.1 Motivation

The prevalent use of 3D technologies has transformed various sectors, but their application in geographical education remains underexplored. The Nottingham Caves, with their rich historical and geological significance, present a unique opportunity to study the potential of PARM to enhance spatial understanding. This research is driven by the potential of PARM to transform educational experiences by providing a more interactive and engaging learning environment (Büyüksalih, G. et al., 2020) (González-Aguilera, D. et al., 2009).

The use of 3D digital surveying and modelling techniques has proven to be a valuable approach for research, management, and preservation of cultural and geological legacies. (González-Aguilera, D. et al., 2009) Recent advances in geotechnologies, such as Lidar and laser scanning, have enabled the exploration of subterranean cave environments and the creation of accurate three-dimensional models. (Basantes, J. et al., 2017) These technologies have allowed for the documentation and preservation of historical and geological features, such as stalagmites, stalactites, and speleothems, which may be susceptible to deterioration and loss due to improper exploitation or lack of knowledge (Basantes, J. et al., 2017).

1.2 Aims and Objectives

Research question: What are the effective methods for assessing understanding gained through (PARM) among school groups and postgraduate students?

Aim: To develop a strategy to assess the understanding gained through PARM displays.

The specific objectives of this study are threefold.

Objectives:

- To measure the effectiveness of PARM displays in enhancing understanding.
- To co-develop educational content, including PowerPoint, 2D maps, and drawing activities.
- To co-develop assessment materials to evaluate understanding gained from PARM.

1.3 Description of the work

The use of technology in education has been a subject of considerable interest in recent years, with numerous studies exploring its impact on student learning and academic performance. This dissertation aims to evaluate the effectiveness of the PARM technology in enhancing educational outcomes, particularly in the study of historical and geographical content.

A mixed-methods approach, combining qualitative and quantitative analysis, will be employed to assess the impact of PARM displays. Educational content will be developed in collaboration with domain experts and tested in ‘City as lab’. The effectiveness of these contents will be evaluated through a combination of standardized tests and feedback from participants, providing a comprehensive assessment of how PARM displays can influence learning outcomes (Gardner et al., 1994; Patero, 2023).

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2. Literature Review

2.1 Early Maps

Early maps, primarily manual in nature, including hand-drawn maps and illustrations, were the foundational tools of traditional cartography. These rudimentary geographic visualizations, dating back to cave paintings, were often limited in accuracy and scope due to the technological constraints of their times (Monmonier, 1981; Library, 2017). The development of cartography, as detailed by Kainz (2020), originated in ancient civilizations such as Mesopotamia, Egypt, and Greece, where maps were created to aid in navigation and the understanding of geographical features **(Figure 2).**

Figure 2: Ptolemy world map (Kainz 2020)

Despite their groundbreaking nature, these early maps struggled with several limitations, most notably their inability to accurately represent the three-dimensional aspects of Earth's landscapes. Techniques like perspective drawing and symbol usage were employed to depict topographical features, but these methods often fell short of capturing the true nuances of the environment (Kainz, 2020). Moreover, the cartographers' limited understanding of the world, compounded by

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cultural biases and incomplete geographical knowledge, often led to maps that were conceptually flawed and technically inadequate (Graeff, C. and Loui, C, M., 2008).

As cartography evolved, propelled by advances in geography, geodesy, and remote sensing, new technologies like computers and digital mapping systems emerged, revolutionizing the field by enabling the creation of more detailed and accurate maps (Başaraner, M., 2015). These advancements addressed many of the earlier limitations, allowing for better representation of geographic data and reducing the distortions caused by inadequate projection techniques (Kainz, W., 2020). The evolution of cartography, therefore, marks a significant journey from basic drawings to sophisticated digital maps, highlighting both historical challenges and technological triumphs in the field.

2.2 Physical Relief Model

Physical relief models have been pivotal in visualizing geographical landscapes and understanding geographical terrains, serving various educational and strategic purposes for centuries (Jang, S., Wakefield, G. and Lee, S., 2017) (Craig, B, A., 2013) (Wang, X., 2009) (Aliakseyeu, D., Martens, J. and Rauterberg, M., 2006). The detailed model of central Switzerland by Pfyffer von Wyer between 1762 and 1786 represents a significant advancement in the art and science of relief modelling during the 18th century **(Figure 3).** These models were primarily crafted for display and educational purposes, providing a tactile way for viewers to grasp complex terrain features (Dowman & Arora, 2012; Niederoest, 2002; Priestnall, 2019).
These tangible three-dimensional representations allowed for a deeper exploration of landscapes, which was essential for tasks like planning and training. Notable developments, such as the 18th-century model of central Switzerland by Pfyffer von Wyer, showcased the effectiveness of these physical models in providing detailed and scaled depictions of geographical regions (Jebur, K, A., 2022).

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Figure 3: Pfyffer's model of Central Switzerland (left) Flintoft's Model of the English Lake District (right) (Priestnall, 2019; Niederoest, 2002)

The development of PARM represents a natural progression from these static models, integrating modern digital technologies to enhance and expand their utility. PARM utilizes digital projection to overlay dynamic geographical information onto physical models, creating an interactive experience that allows for real-time updates and data manipulation. This integration caters to the increasing demand for more interactive and engaging educational tools in museums, academic settings, and public displays (Priestnall and Cheverst, 2019).

Research indicates that physical models, by their very nature, offer advanced engagement through kinaesthetic interaction, significantly enhancing the understanding and retention of geographical features compared to traditional 2D maps or monitor-based visualization techniques (Mitsova et al., 2006; Lovett et al., 2015). The incorporation of digital enhancements in PARM builds upon this foundation by adding layers of interactivity and multimedia elements that increase the realism and applicability of the models for various educational and planning purposes.

Contemporary physical relief models, augmented with digital textures and interactive elements, provide immersive experiences that were previously unattainable. For instance, the use of PARM to show the causes and impacts of flooding (including the areas likely to flood, the benefit of

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flood alleviation and the impacts of climate change) (JBA Trust, n.d.). PARM can be used to demonstrate a variety of scenarios on a physical 3D model of a landscape or town **(Figure 8).**

Using a 3D model makes it easier to understand complex spatial information, especially where it changes over time or in different scenarios, for example, the impact of climate change on flood risk. Accompanying images displayed alongside the 3D map projections help users interpret the information on the map in land use planning and environmental management allowing stakeholders to interactively engage with the model, contributing to more informed decision-making processes. This is evident in scenarios such as participatory watershed management projects, where three-dimensional topographic models have facilitated critical discussions and decisions among local stakeholders (Hoare et al., 2001).

2.3 Virtual (VR) and Augmented Reality (AR)

The rapid advancements in technology have significantly altered our interaction with and perception of the world. Introduced by Milgram in 1994, the concept of mixed reality has expanded the boundaries of geographical data interaction and comprehension (Huang, T. et al., 2023). At the forefront of this revolution are augmented reality (AR) and virtual reality (VR) technologies, such as the Oculus Rift, which create immersive environments where digital and physical realities converge (Skarbez, R., Smith, M. and Whitton, C, M., 2021).

Milgram and Kishino's reality-virtuality continuum illustrates **(Figure 4)** a spectrum from fully real to fully virtual environments, with AR and augmented virtuality inhabiting the intermediate spaces. The notion of "pervasive virtuality" integrates physical environments and objects into virtual settings, enhancing the depth and context of user interactions (Milgram, P., & Kishino, F., 1994).

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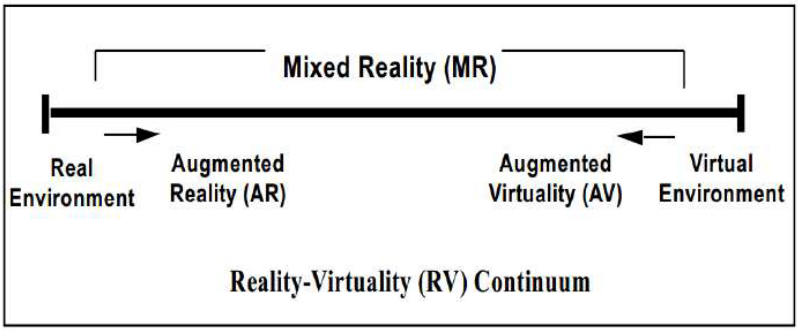

Figure 4: Simplified representation of a RV Continuum. (Milgram, 1994)

The advent of wearable devices **(Figure 5)** such as Microsoft HoloLens, Oculus Rift Visor, Magic Leap, and Epson Moverio Smart Glasses has significantly advanced AR and VR applications, allowing for more integrated experiences across various domains, including urban planning, healthcare, and education (Olmedo, H., 2013; Endsley, T. et al., 2017; Maimone, A., Georgiou, A. and Kollin, J., 2017; Kim, H. et al., 2020; Luis, M, E, C. et al., 2017).

Figure 5: Oculus Rift visor (left), the rotation of Oculus Rift (right) (Goradia, Doshi & Kurup,2014)

In education, AR and VR technologies have been leveraged to provide contextual information that simplifies complex concepts, enhancing learning experiences by allowing real-time manipulation of educational content (Luis, M, E, C. et al., 2017). Industrial and educational settings have benefited from AR applications like Google Glass and HoloLens, which deliver critical information to streamline complex tasks (Luis, M, E, C. et al., 2017).

Despite their potential, AR and VR technologies face significant challenges, such as cumbersome form factors that do not align well with human dynamics. Ongoing research aims to overcome these barriers by developing devices that are more adaptable to human physiology, enhancing the naturalness of the VR/AR experience (Yin, J. et al., 2020). As AR and VR technologies continue to evolve, their potential to transform various sectors is immense. With continued investment and research, these technologies are set to become more accessible and integrated into daily life, promising revolutionary changes in how we interact with and understand our world.

2.4 Projected Augmented Relief Models (PARM)

Projected Augmented Relief Models (PARM) integrate advanced digital technologies with physical relief models, presenting a transformative approach to the visualization and interaction with geographical data. The Projected Augmented Relief Model (PARM) was developed through a collaboration between geographer Priestnall and artist Gardiner during their residency at the University of Nottingham's 'Towards Pervasive Media' project. Their work focused on the intersection of landscape representation and digital media, specifically using the English Lake District as their subject of study (Priestnall et al., 2012).

PARM represents a significant advancement from traditional relief models, which were primarily used for military and educational purposes. The physical model for the Projected Augmented Relief Model (PARM) display **(Figure 6)** was designed to be large enough for public viewing, specifically at least 50cm by 50cm. The model focuses on the upper surface, which is shaped using subtractive fabrication techniques—a method where material is precisely removed to create a specific form. Various tools like drills, lathes, grinders, and lasers can be used for this purpose, but for greater precision and efficiency, a Computer Numerically Controlled (CNC) milling

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machine was selected, specifically the Roland MDX 540. This approach was preferred over additive methods like 3D printing due to its cost-effectiveness, durability, and speed. The lightweight high-density foam board was chosen as the material for the prototype due to its ease of handling and suitability for the milling process (Priestnall et al., 2012).

Figure 6: Creating the PARM prototype: Hillshade view of the DSM of Cumbria (left); The milling of one tile (centre); The prototype PARM system (right) (Priestnall et al., 2012).

This innovative approach enhances the traditional static model by adding layers of digital information that can be updated and manipulated interactively (Priestnall et al., 2012; Khaitov, 2019). The evolution of this technology reflects broader trends in digital geography and interactive design, where the goal is to make spatial data more accessible and understandable to a broader audience.

PARM has been effectively deployed in various public settings, including museums, educational institutions, and community centres **(Figure 7).** The "Spots of Time" display at the Wordsworth Trust utilized PARM to enrich visitors' experiences by providing a geographical context to literary works, thereby bridging the gap between textual content and physical geography (Liu, 2020).

Additionally, collaborations with entities like JBA Consulting and the Environment Agency have demonstrated the utility of PARM in environmental education and planning, where it has been used to simulate flood events and other environmental scenarios, facilitating a better understanding of these complex issues among stakeholders (Craig, 2013; Bennett et al., 2012; JBA Trust, 2021).

Figure 7: PARM for Keswick School (left), (www.nottingham.ac.uk, n.d.); JBA Consulting (right) (JBA Trust, n.d.).

The interactivity provided by PARM significantly enhances learning outcomes by promoting active engagement with the content. Users are not merely passive recipients of information but active participants in exploring and manipulating spatial data. This engagement is particularly effective in educational settings where understanding the spatial context is essential. Studies have indicated that PARM improves spatial cognition and increases retention rates of geographical and environmental information among learners of all ages (Leopardi et al., 2021; Arss, Smith, and Priestnall, 2017). Furthermore, the tactile nature of PARM models helps to solidify abstract concepts into concrete understanding, making it an invaluable tool in geographic education.

Despite its many advantages, the deployment of PARM is not without challenges. The technology requires significant initial investment in hardware and software, and there is a continuous need for technical expertise to maintain and update the digital components of the models. Additionally, there are challenges related to the scalability of PARM applications and their adaptability to different environmental and educational contexts. Future research should

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focus on developing more user-friendly interfaces and exploring cost-effective materials and methods to broaden the accessibility of PARM. Researchers are also encouraged to investigate the long-term impacts of PARM on learning and public engagement, particularly in terms of enhancing participatory decision-making in community and environmental planning (Priestnall et al., 2012; Sprinks et al., 2020).

Projected Augmented Relief Models have proven to be a powerful tool in the arsenal of geographic and environmental education, offering dynamic and engaging ways to explore complex data sets. As the technology advances, it holds the promise of revolutionizing the way we interact with and understand geographical information, making it more accessible to diverse audiences across educational, professional, and public domains.

2.5 Review of Related Work

The integration of digital technologies with physical models through Projected Augmented Relief Models (PARM) has proven to be a valuable tool for enhancing public engagement and spatial understanding. Noted by multiple studies, PARM facilitates interactive and immersive experiences in educational and environmental contexts (Priestnall et al., 2012; Khaitov, 2019; Craig, 2013; Zhang, L., Zhang, S., and Lang, Y., 2020). Demonstrations such as the "Spots of Time" at the Wordsworth Trust and collaborative efforts with entities like JBA Consulting and the Environment Agency have showcased PARM's utility in making complex spatial information accessible and engaging (Liu, 2020; Bennett et al., 2012; JBA Trust, 2021; Wang, X. et al., 2007.

Al-Douri, F., 2010). However, there remains a need for more rigorous quantitative research and a thorough examination of the deployment challenges to optimize its use and broaden its application (Leopardi et al., 2021). The integration of physical models with dynamic digital projections through touch-based interactivity has garnered significant attention for its innovative approach in the realm of interactive visualization. Arss, Smith, and Priestnall's study

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in 2017 marked a pivotal moment in recognizing the potential of this technology to enhance user engagement and deepen understanding of complex information. Their work, while pioneering, has been noted for its need for additional quantitative data and a thorough examination of the technological challenges that such an integration entails (Craig, 2013; Alcañíz, M., Alcañiz, B, E, J., and Guixeres, J., 2019; Jang, S., Wakefield, G., and Lee, S., 2017).

Subsequent investigations have aimed to address these gaps by adopting a comprehensive mixed-methods research approach, which combines quantitative and qualitative analyses to capture a fuller picture of the impact and usability of combining physical models with digital projections. This research strategy has proven effective in validating the benefits highlighted in previous studies, particularly regarding enhancements in user interaction and educational outcomes.

Quantitative results from these studies have consistently shown significant improvements in user engagement metrics. For instance, Fonseca, Domínguez, and Villagrasa's research in 2014 revealed notable increases in student motivation and academic performance when utilizing these hybrid visualization tools within educational settings. Their findings are supported by additional studies that also demonstrate the positive effects of interactive and collaborative tools on student motivation, particularly among architecture and building science students (Fonseca, D., Domínguez, R, E., and Villagrasa, S., 2014).

Moreover, the application of dynamic digital projections on physical models has been shown to enhance spatial understanding, which is crucial for students engaged in disciplines that require a strong grasp of three-dimensional space and design. This improvement in spatial skills is particularly valuable, providing a tangible benefit that underscores the practical implications of integrating advanced visualization technologies in educational curricula.

In summary, while the initial research into the integration of physical models with dynamic digital projections highlighted promising potential, ongoing studies have begun to substantiate these claims with solid empirical evidence. The continuous refinement of research methodologies and the expansion of study contexts are crucial for overcoming the initial challenges and unlocking the full potential of this innovative visualization technology.

The integration of educational technologies, particularly augmented reality (AR), has profoundly enhanced learning environments, significantly boosting student engagement and outcomes (Liu, 2020; Jwaifell, 2019). AR technology facilitates the merging of computer-generated virtual information with real-world settings, thereby offering innovative educational methods and creating engaging learning experiences. In museums, Chen and Lai (2021) employed structured questionnaires and Partial Least Square (PLS) modeling to measure learning motivation and effectiveness, further advocating the use of qualitative methods to gain deeper insights (Sommerauer and Müller, 2014). This approach has been paralleled in other studies, which have demonstrated that AR can substantially improve teaching and learning experiences by offering new opportunities for designing engaging learning environments (Bacca, J. et al., 2014; Phon, E, N, D., Ali, B, M., and Halim, A, D, N., 2014).

Research has consistently shown that AR enhances students' cognitive abilities, motivation, and overall learning outcomes, making it a valuable tool in educational settings. The potential for collaborative AR to enrich educational experiences has also been highlighted, underscoring its efficacy in increasing students' engagement and understanding (Phon, E, N, D., Ali, B, M., and Halim, A, D, N., 2014). However, the effective design and implementation of AR are crucial; while AR holds significant pedagogical value, the careful design of AR applications to support learning activities is essential for realizing its full educational potential.

The integration of mixed methods in augmented reality simulations has proven effective in providing a more nuanced understanding of their impact on educational outcomes. Dunleavy, Dede, and Mitchell (2008) emphasized the potential of this approach, suggesting that combining quantitative data with qualitative insights can enrich the assessment of augmented reality's effectiveness in learning environments. This perspective is supported by further research indicating the robustness of mixed methods in delivering comprehensive insights into educational technologies (Aresti-Bartolome, N. and García-Zapirain, B., 2014; Thomas, H, B., 2012; Hughes, E, C. et al., 2005).

Additionally, Bangay and McKenzie (2022) argue for the strategic use of both quantitative and qualitative approaches to yield more reliable findings. This methodological synergy is evident in studies across various educational contexts, enhancing the understanding of technologies' roles in diverse learning scenarios (Gaol, L., F. and Prasolova-Førland, E., 2021). Specifically, augmented reality's capability to simulate realistic educational settings offers valuable insights into addressing sensory challenges faced by individuals with autism spectrum disorder, blending measured outcomes with experiential feedback (Aresti-Bartolome, N. and García-Zapirain, B., 2014).

Moreover, the application of mixed methods helps overcome the limitations associated with single-method studies, as noted in a meta-analysis by Cao, W. and Yu, Z. (2023), which advocates for larger and more varied sample sizes to reduce sample bias and enhance the understanding of augmented reality's specific features and pedagogical effectiveness.

Drawing on these insights, future research on PARM should focus on designing and evaluating both quantitative and qualitative methodologies to capture the engagement, learning, and spatial understanding of users interacting with these displays. This would involve structured surveys to gather quantitative data on user engagement and learning outcomes, coupled with qualitative interviews to gain deeper insights into user experiences and perceptions.

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3. METHODS

This chapter delineates the comprehensive methodology adopted to explore the educational implications of the Projected Augmented Relief Model on spatial learning capabilities among varied academic levels. Employing a mixed-methods approach, this study integrates qualitative observations with quantitative data analysis, aiming to thoroughly assess how interactive learning tools can significantly enhance educational experiences within the domain of geospatial sciences (Bistaman, M, N, I., Idrus, S, Z, S. and Rashid, A, S., 2018) (Cheng, K. and Tsai, C., 2012) (Fonseca, D. et al., 2014) (Nellis, M., 1994). The investigation seeks to understand the extent to which such technologies can transform traditional learning paradigms and foster a deeper engagement with the subject matter.

3.1 The 'City as Lab' Facility

The 'City as Lab' facility at Fitzroy House on the Castle Meadow campus in Nottingham (**Figure 9)** served as both a consultation and research space for this study. Equipped with state-of-the-art resources including GPU computers, mobile display screens, and flexible exhibition areas, the facility facilitated the diverse range of activities central to this research (Cheng, D. et al., 2020). These activities included collaborative workshops and informal interactions, supported by the layout of the facility which features distinct areas such as the 'Collaboration' area, capable of hosting 30-50 individuals, and the 'Curiosity' area, designed for displays and informal exchanges (www.nottingham.ac.uk, n.d.).

The Nottingham Urban Room within the 'City as Lab' provided a neutral space for stakeholder dialogues about urban development in Nottingham, which was instrumental in fostering inclusive discussions and gathering diverse stakeholder perspectives, essential for the participatory approach of the study. This method aligns with established research on the effectiveness of community engagement and participatory practices in urban planning (García-Berrocal, R, J., 2017).

In summary, the 'City as Lab' not only supported the logistical execution of the study but also enriched the research process by facilitating a dynamic environment for community involvement and interactive learning. This integration of technological and spatial resources with participatory practices was crucial in advancing the research objectives, emphasizing the facility's role in enhancing urban studies through collaborative and inclusive methodologies (Cheng, D. et al., 2020).

Figure 8: City as Lab at Castle Meadow (www.nottingham.ac.uk, n.d.)

3.2 A Case Study of the Nottingham Caves

The Nottingham Caves **(Figure 9)** offer a compelling case study for using immersive technologies like the Projected Augmented Relief Model (PARM) to enhance heritage education. The integration of PARM into the educational framework helps illuminate Nottingham's rich history in an engaging and interactive manner, aligning with the city council's educational goals (Yiğit, Y, A., Ulvi, A. and Varol, F., 2020; Chevallet, J. and Lim, K, C., 2017; Han, S., Yoon, J. and Kwon, J., 2021). The use of the Projected Augmented relief Model (PARM) in this context allows for the creation of dynamic, multidimensional environments that make historical artifacts and sites more accessible and comprehensible to visitors, enhancing their understanding of the

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site’s cultural and historical significance.

Figure 9: Projection of Nottingham Caves Contents on the Large Nottingham PARM Model at Castle Meadow in Nottingham

3.3 Collaborative Content Curation and Evaluation

The creation of the content of the Nottingham caves for the Projected Augmented Relief Model **(Figure 9, 10)** was a collaborative effort involving researchers from the University of Nottingham and the Nottingham City Council. An archaeologist and a geographer from the University of Nottingham worked together to curate the content for this project, which aimed to aid the city council's planning initiatives (González-Aguilera, D. et al., 2009). The team also developed 2D maps and co-designed TV presentation materials, as well as resources for drawing activities.

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The evaluation materials **(Appendix)** were jointly created by students from the Horizon team at the University of Nottingham and the Nottingham City Council, ensuring that both educational and municipal perspectives were integrated into the assessment tools. This approach of incorporating diverse stakeholders and expertise aligns with recent trends in the field of digital heritage, where researchers have emphasized the importance of collaborative curation and evaluation processes to ensure the relevance and effectiveness of digital tools and resources (Landeschi, G. et al., 2020).

Figure 10: Development of Educational Materials for Hollygirt Independent School.

3.4 Participants

Participants were categorized into two distinct groups based on their educational levels:

3.4.1 School Children

Comprising 49 pupils from Hollygirt Independent School in Nottingham, the children were divided into sessions based on their age—Years 5 and 6 during the morning and Years 7 and 8 in the afternoon, with activities conducted on July 3, 2024 **(Figure 11).**

3.4.2 Postgraduate Students

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This group included individuals recruited from the University Park and Jubilee Park campuses at the University of Nottingham in Nottingham **(Figure 13)**, participating in a structured experiment involving pre-and post-test assessments to evaluate spatial learning outcomes, conducted on August 1, 2024.

The selection of participants for the study was purposive, targeting specific age groups and educational levels to investigate the research questions effectively (Halim, A, H, T, R., Supriatno, B. and Amprasto, A., 2021) (Annandale, R., 2019) (Alghamdi, M. et al., 2016). The researchers ensured that the participants were properly informed about the study's purpose and provided clear instructions before the data collection process. (Alghamdi, M. et al., 2016) The participation was voluntary, and the researchers took measures to maintain the confidentiality of the participants' information (Kutywayo, A. et al., 2022).

The study's methodology for the participation of the two groups was tailored to their respective contexts. For the school children, the researchers collaborated with the school administration to organize the sessions during regular school hours, minimizing disruption to the students' routine (Kobayashi, H. et al., 2018). In contrast, the postgraduate students were recruited from the university campuses, participating in a more structured experimental design involving pre- and post-test assessments (Kutywayo, A. et al., 2022).

The researchers employed strategies to ensure the validity and reliability of the data collected from the participants. For instance, the researchers took measures to maintain the participants' anonymity and create an environment that encouraged honest and unbiased responses (Pákozdy, C. et al., 2023; Kutywayo, A. et al., 2022; Alghamdi, M. et al., 2016; Kobayashi, H. et al., 2018). The study's findings, therefore, provide valuable insights into the spatial learning outcomes of the two distinct educational groups, contributing to the understanding of factors that influence such cognitive processes (Alghamdi, M. et al., 2016; Pákozdy, C. et al., 2023).

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3.5 Data Collection Methods

The study employed **(Figure 11, 12)** a multi-pronged approach to data collection, leveraging a combination of traditional and emerging methods to maximize the depth and breadth of insights (Fonseca, D. et al., 2014; Jarvis, C. et al., 2015). The school group sessions were designed to alternate between the use of PARM and traditional 2D maps, with the goal of enhancing engagement and learning outcomes. These sessions were facilitated by fourteen adults who played pivotal roles, including leading demonstrations, managing interactions, conducting direct observations, handling photographic documentation, and overseeing educational presentations.

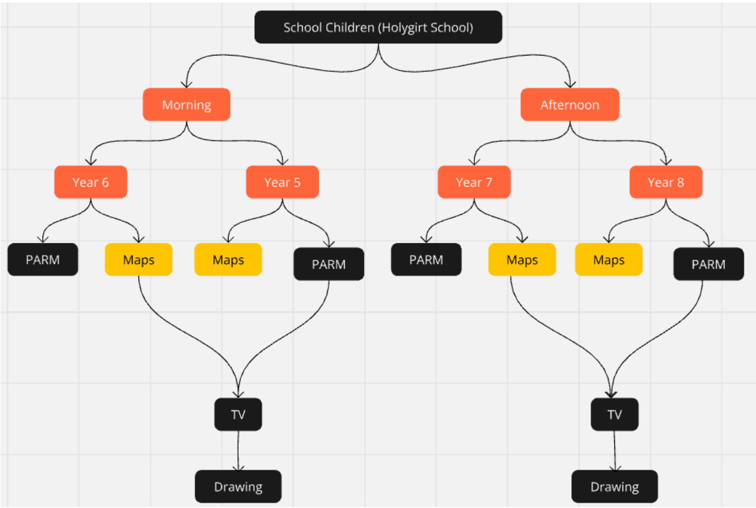

Figure 11: Educational Schedule and Tools Used for School Children at Hollygirt School. This flowchart details the distribution of educational tools and media (PARM, Maps, TV, Drawing) among different year groups (Year 5 to Year 8) during morning and afternoon sessions.

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Figure 12: Educational activities with Hollygirt Independent School on 03/07/2024, showcasing children from Years 5 to 8 engaging with PARM (bottom left), 2D printed maps (Top images), and drawing activities (bottom right). This figure captures moments from both morning and afternoon sessions.

The postgraduate student **(Figure 13)** segment involved a sequence of structured activities that began with initial briefings to introduce the study objectives, followed by consent verifications, interactive sessions with PARM, and detailed post-session assessments to gauge the effectiveness of the learning tools used (Xie, Y., Chen, Y. and Ryder, H, L., 2019) (Fonseca, D. et al., 2014). The methodology for PARM was carefully designed to ensure a rigorous and systematic approach to data collection, drawing on best practices from the field of educational research (Sorby, S., 2009).

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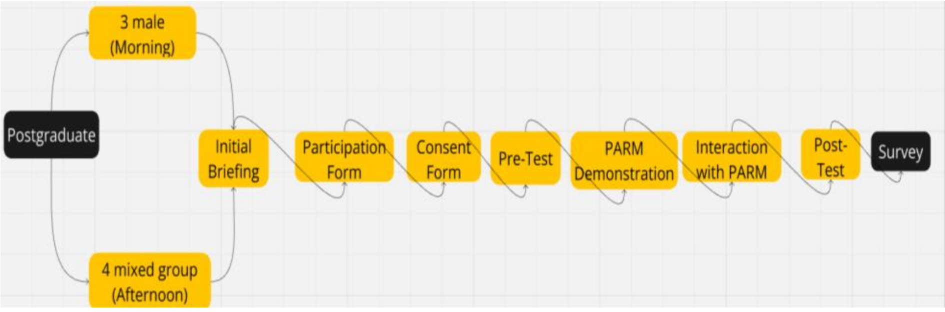

Figure 13: Workflow for the postgraduate study conducted on August 1, 2024 (top), detailing sequential activities from the initial briefing to the final survey for two groups: a male group in the morning and a mixed -gender group in the afternoon(bottom)

3.6 Data Analysis

The analysis framework implemented in this study incorporated both quantitative and qualitative methodologies to provide a comprehensive evaluation of the educational interventions, utilizing tools such as Google Colab Python for data analysis and manipulation (Ji, Y., 2020; Konrad, A. and Galguera, T., 2018). This mixed-methods approach allowed for a robust assessment of the interventions, combining statistical analysis and thematic interpretation to draw nuanced insights from the gathered data. The use of Google Colab Python specifically facilitated the efficient handling and processing of large datasets, enhancing the analytical capabilities necessary for this detailed evaluation.

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3.6.1 Quantitative Analysis

The quantitative analysis involved the meticulous examination of data gathered from structured surveys and tests. Descriptive and inferential statistical techniques were utilized to quantify learning outcomes and assess the effectiveness of the educational interventions (Martínez-Monés, A. et al., 2003) (Palinkas, A, L., Mendon, J, S. and Brown, A., 2019). The application of these rigorous analytical methods enabled the researchers to identify statistically significant trends and patterns in the data, offering valuable insights into the impact of educational tools on student learning.

3.6.2 Qualitative Analysis

Parallel to the quantitative analysis, a qualitative approach was employed to uncover deeper insights into the participants' learning processes and interactions with the educational tools. Thematic analysis of the observational data and interview transcripts was conducted, revealing underlying patterns and providing a richer understanding of the nuances inherent in the educational experience. (Lowry, H, O. et al., 1951) (Palinkas, A, L., Mendon, J, S. and Brown,
A., 2019). The integration of these complementary analytical approaches, combining quantitative and qualitative methodologies, allowed the researchers to develop a multifaceted understanding of the educational interventions and their effectiveness.

3.7 Ethical Considerations in Engineering Research

Ethical considerations are of paramount importance in the conduct of engineering research, particularly when human participants are involved. In the present study, the researchers obtained ethical approval from the Faculty of Engineering's review board, ensuring that the proposed research met the necessary standards for the protection of human subjects.
Detailed consent forms **(Appendix)** were distributed to all participants, informing them of the

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study's purpose, their rights to confidentiality, and the voluntary nature of their participation. This aligns with the principles outlined in the Declaration of Helsinki and the Ethical Guidelines for Nursing Research, which emphasize the importance of obtaining informed consent and minimizing the risks to participants.

The researchers also took measures to ensure the confidentiality and anonymity of the study participants. These practices are crucial in maintaining the trust and privacy of the individuals involved, as highlighted in the findings of a study on graduate students' research ethics practices. (Swedan, S. et al., 2020) By adhering to these ethical principles, the researchers aimed to uphold the highest standards of integrity and respect for the participants in this engineering research project.

3.8 Challenges in Recruiting and Engaging

Recruiting participants for research can present significant hurdles, particularly when targeting specific populations such as postgraduate students and coordinating logistics with schools (Sternlieb, G., 1968). The study faced several limitations that hindered the execution and findings, including challenges with participant recruitment, scheduling and logistics, and availability of participants (Taghap, S, R., 2023; Garavan, H. et al., 2018).

Participant recruitment proved particularly difficult, with low engagement rates among postgraduate students and logistical issues with school recruitment (Mirick, G., R., 2014). Previous research has highlighted the challenges of recruiting hard-to-reach populations, such as the use of non-probability sampling methods that can introduce sampling bias and threaten the validity of findings (Mirick, G., R., 2014). To mitigate these issues, researchers must carefully design recruitment strategies that foster a collaborative attitude between the study team, schools, and local communities (Garavan, H. et al., 2018) The timing of ethical approvals also caused delays, further complicating recruitment efforts as the approval process meant that undergraduate students were unavailable during the summer break.

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4. Results

The results section presents a detailed analysis of the data collected through various research methods to assess the impact of PARM on educational outcomes. It encapsulates the quantitative improvements in learner engagement and comprehension, supported by statistical analyses and qualitative feedback from participants. This section elucidates how PARM enhances learning experiences compared to traditional educational tools.

4.1 School Children's Results

4.1.1 Children's Survey

The data gathered from the children's survey at Hollygirt Independent School will be analyzed in this section. This analysis will help illustrate how effectively the interactive displays enhanced learning and engagement among the students.

1. **Excitement**:

   The bar chart illustrates **(Figure 14)** the preferences of respondents regarding which display type they found most exciting. The 3D model was the most popular, receiving the highest number of responses, significantly outpacing printed maps and TV presentations. This suggests a strong preference for interactive and immersive formats among the viewers.

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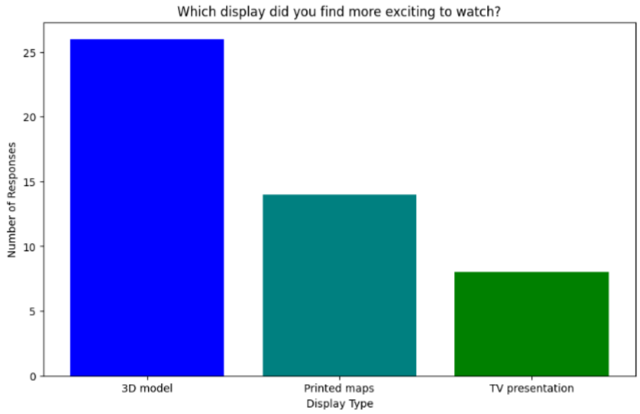

Figure 14: Which display did you find more exciting to watch?

2. **Ease of Understanding:**

   The bar chart reveals **(Figure 15)** that the 3D model display significantly captivated the audience more than the other types, with it receiving the highest number of positive responses. Printed maps were moderately popular, and TV presentations garnered the least interest among the viewers. This suggests a strong preference for interactive and visually engaging formats.

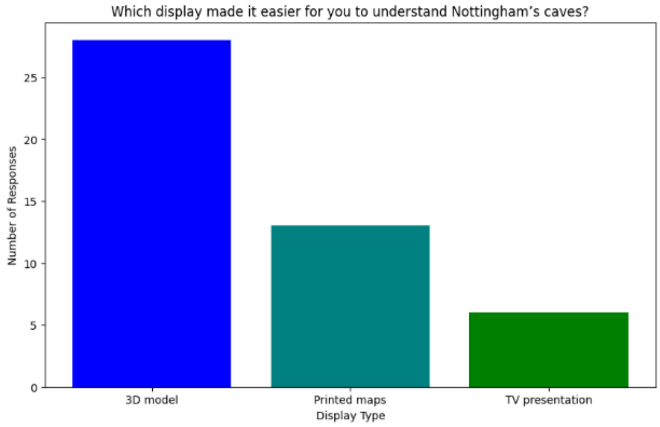

Figure 15: Which display made it easier for you to understand Nottingham's caves?

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3. **Informational Value**:

   The bar chart **(Figure 16)** indicates that the 3D model display was most effective in providing information about Nottingham's caves, as perceived by the respondents. It received the highest number of responses, suggesting it was the most informative. The printed maps and TV presentations, while still useful, were considered less informative in comparison. This reflects the 3D model's ability to offer a more detailed and engaging exploration of the caves' features.

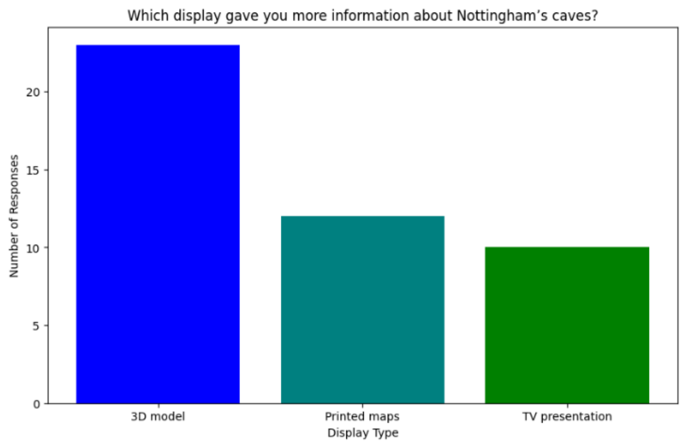

Figure 16: Which display gave you more information about Nottingham's caves?

4.1.2 Children's Survey - Likert Scale

The Likert scale in the children's survey evaluates excitement, information delivery, and understanding for display types: Projected Augmented Relief Model (PARM), maps, and TV presentations, providing insights into children's engagement and learning experiences.

1. **Excitement**

   The stacked bar chart **(Figure 17),** the provided statistical data, indicates that the Projected Augmented Relief Model (PARM) was the most exciting display type for the children, as evidenced by the highest mean score of 4.0 and a standard deviation of 1.1.

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This suggests a generally positive response with some variation in opinion **(Table 1).** Both the 2D printed maps and TV presentations received lower mean scores of 3.3, with similar levels of variability in responses (standard deviations of 1.2 and 1.1, respectively), indicating they were somewhat less exciting compared to PARM.

The statistical analysis **(Table 2)** includes an F-statistic of 4.7 with a p-value of 0.01. This indicates that there is a statistically significant difference in how exciting the children found the different display types, with PARM being more positively received than the others. The p-value confirms that the observed differences in excitement levels across the display types are unlikely to be due to chance.

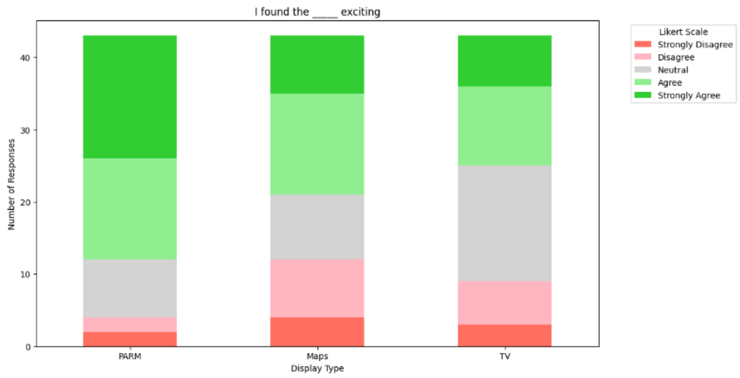

Figure 17: I found this display exciting

Table 1: **Descriptive Statistics (**I found this display exciting)

	Mean	**Standard Deviation**
PARM	4.0	1.1
2D Printed Maps	3.3	1.2
TV presentation	3.3	1.1

Table 2: **Inferential Statistics (**I found this display exciting**)**

F-statistic	4.7
p-value:	0.01

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2. **Informational Value**

The provided stacked bar chart **(Figure 18)** and statistics suggest that all three display types—Projected Augmented Relief Model (PARM), 2D printed maps, and TV presentations—were found to deliver information about the caves effectively, with PARM slightly leading in terms of perceived informativeness.

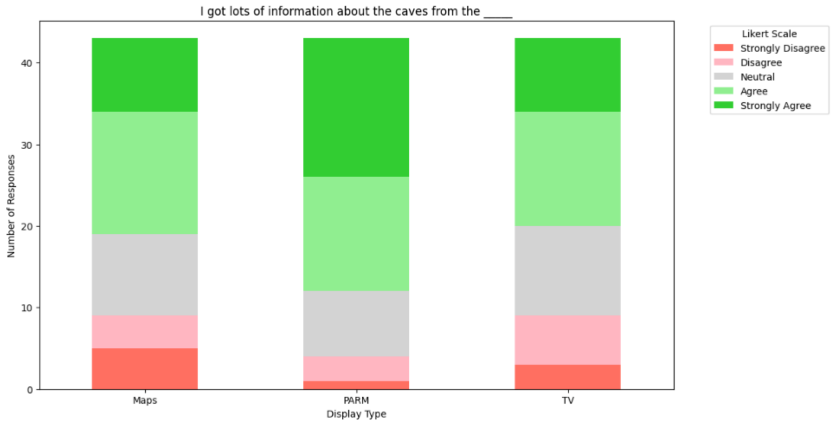

Figure 18: I got lot of information about the caves from the __

Descriptive Statistics (Table 3): PARM: This had a mean score of 4.0 with a standard deviation of 1.0, indicating a high level of perceived informativeness with some variability in responses. **2D Printed Maps and TV Presentations**: Both received mean scores of 3.5. The slightly higher standard deviation for maps (1.3) compared to TV presentations (1.2) suggests a broader range of responses on the effectiveness of maps in conveying information.

Table 3: **Descriptive Statistics (**I got a lot of information about the caves from the __**)**

	Mean	**Standard Deviation**
PARM	4.0	1.0
2D Printed Maps	3.5	1.3
TV presentation	3.5	1.2

Inferential Statistics (Table 4): The **F-statistic of 3.2** and a **p-value of 0.05** indicate that there are statistically significant differences in the levels of information delivery across the three

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display types. This statistical outcome suggests that while differences exist, they are subtle, especially between maps and TV presentations compared to PARM.

Table 4: **Inferential Statistics (**I got a lot of information about the caves from the __**)**

F-statistic	3.2
p-value:	0.05

3. **Ease of Understanding**

Overall, the analysis suggests **(Figure 19)** that while PARM was rated slightly higher for ease of understanding, the differences across all three display types are not substantial enough to be statistically significant. This implies that each display type could be similarly effective in educational contexts, depending on other factors like specific content and presentation style.

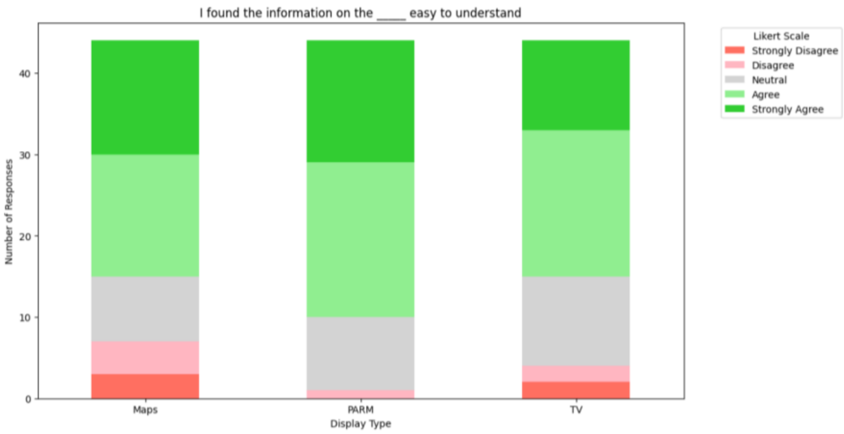

Figure 19: I found it easy to understand

Descriptive Statistics (Table 5): PARM: With a mean score of 4.1 and a standard deviation of 0.8, PARM leads in perceived ease of understanding, indicating a more consistent and higher level of clarity among respondents. **2D Printed Maps and TV Presentations:** Both received mean scores of 3.8. Maps had a higher standard deviation (1.2) compared to TV presentations (1.0), suggesting a slightly wider variation in responses regarding maps

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Table 5: **Descriptive Statistics** (I found it easy to understand**)**

	Mean	Standard Deviation
PARM	4.1	0.8
2D Printed Maps	3.8	1.2
TV presentation	3.8	1.0

Inferential Statistics (Table 6): The **F-statistic of 1.5** and a **p-value of 0.2** indicate that the differences in perceived ease of understanding among the three display types are not statistically significant. This suggests that while there are some preferences among children for PARM, these do not differ significantly from the other methods statistically.

Table 6: **Inferential Statistics (**I found it easy to understand**)**

F-statistic	1.5
p-value:	0.2

4.1.3 Children's Survey – Gender

The bar chart **(Figure 20)** and associated statistics assess the excitement scores for different display types (PARM, Maps, and TV presentations) across gender.

Gender-based Excitement Scores:

Males found PARM most exciting (mean: 4.4), significantly more than maps (mean: 3.3) and TV presentations (mean: 3.8) **(Table 6**). The lowest variability (standard deviation: 0.7) in responses was for PARM, indicating strong and consistent preference.
Females showed a preference for maps (mean: 3.5) over PARM (mean: 3.3) and TV presentations (mean: 2.6). The responses for females had slightly higher variability compared to males, particularly for PARM.

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ANOVA Results (Table 9):

PARM and TV presentations showed significant gender-based differences in excitement scores, with **F-statistics of 16.3 and 16.4**, respectively, both having extremely low p-values (around 0.0002). This indicates a statistically significant difference in how males and females perceived the excitement of these displays, with males showing a stronger preference for PARM and females finding it less exciting.

Maps did not show a significant difference in excitement scores between genders (F-statistic: 0.3, p-value: 0.596), indicating that the level of excitement induced by maps was more uniformly perceived across genders.

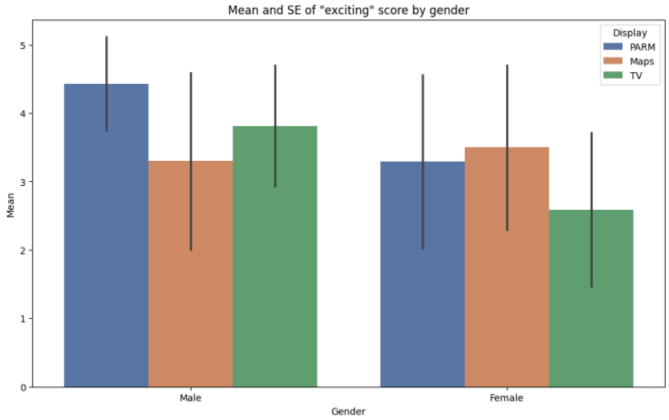

Figure 20: Gender-based Excitement Scores

Table 7**: Mean** (Gender-based Excitement Scores)

Gender	PARM	MAPS	TV
Female	3.3	3.5	2.6
Male	4.4	3.3	3.8

Table 8: **Standard Deviation (**Gender-based Excitement Scores**)**

Gender	PARM	MAPS	TV
Female	1.3	1.2	1.1
Male	0.7	1.3	0.9

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Table 9: **ANOVA Results** (Gender-based Excitement Scores)

	F-statistic	p-value
PARM	16.3	0.000208
Maps	0.3	0.596
Tv	16.4	0.000216

4.1.3 Children's Survey – Correlation

The heatmap reveals the correlation **(Figure 21)** between excitement, understanding, and information scores for PARM, maps, and TV methods. For PARM, there is a moderate positive correlation between "Exciting" and "Understanding" (r = 0.40) and between "Exciting" and "Info" (r = 0.32). Understanding and info scores also show a positive correlation (r = 0.37). Maps display the highest correlation between "Exciting" and "Understanding" (r = 0.62), indicating a strong link between these scores. The correlation between "Exciting" and "Info" for maps is moderate (r = 0.38), while "Understanding" and "Info" are positively correlated (r = 0.47). For TV, "Exciting" and "Understanding" have a low positive correlation (r = 0.23), while "Exciting" and "Info" show a moderate positive correlation (r = 0.33), and "Understanding" and "Info" have a positive correlation (r = 0.39). Additionally, "PARM Exciting" correlates moderately with "TV Exciting" (r = 0.41), but "Maps Exciting" and "TV Exciting" have a negative correlation (r = -0.17). Overall, the highest correlations are within the same method, particularly for maps, where the excitement is strongly linked to understanding (r = 0.62). Excitement scores for PARM and TV are also moderately correlated (r = 0.41).

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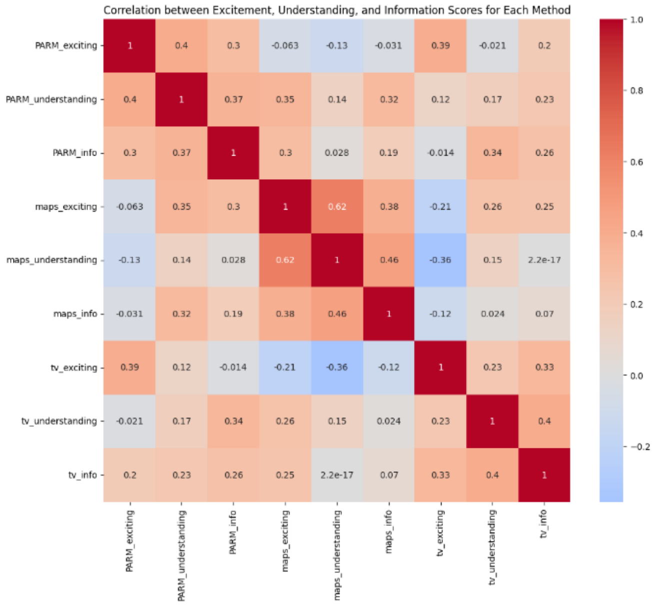

Figure 21: correlation between excitement, understanding, and information scores

4.1.4 Direct Observation

Year 5: The bar chart **(Figure 22)** presents the scores from direct observation of **Year 5** school children engaging with two different types of displays: 2D Printed Maps and Projected Augmented Relief Model (PARM). The evaluation criteria include Engagement Level, Comprehension, Emotional Response, Interaction Quality, and Collaboration.

Analysis of the Observations:

1. **Engagement Level**: PARM scored higher than 2D printed maps, suggesting that the interactive and immersive nature of PARM more effectively captures and holds the attention of Year 5 students.

2. **Comprehension**: Both PARM and 2D printed maps scored similarly in comprehension. This indicates that while PARM may be more engaging, both mediums are equally effective in facilitating understanding of the presented content.

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3. **Emotional Response**: PARM elicited a higher emotional response compared to 2D-printed maps. This might be due to the dynamic and visually appealing nature of the PARM, which can evoke stronger feelings and a more memorable experience.

4. **Interaction Quality**: PARM again scored higher, likely because it allows for more hands-on experience, which can enhance the quality of interaction and engagement with the content.

5. **Collaboration**: Both PARM and 2D printed maps foster similar levels of collaboration among students. This suggests that both formats provide sufficient opportunity for students to work together and learn collaboratively.

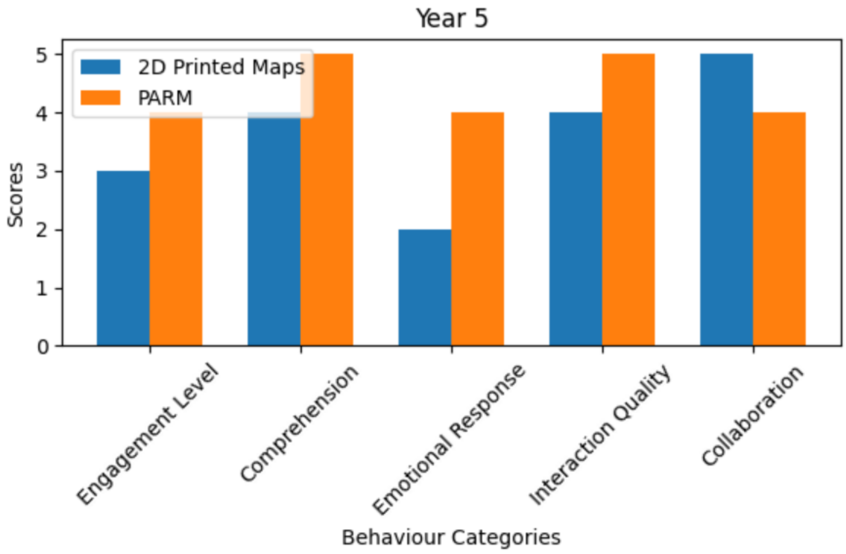

Figure 22: Year 5

Year 6: The bar chart displays **(Figure 23)** scores from direct observations of **Year 6** students interacting with 2D Printed Maps and Projected Augmented Relief Model (PARM) across various behavioural categories.

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Analysis of the Observations:

1. **Engagement Level**: PARM significantly outperformed 2D printed maps in engagement, suggesting that PARM's interactive features greatly captivate and hold the attention of Year 6 students.

2. **Comprehension**: PARM also leads in comprehension, indicating that its dynamic and immersive approach not only captures attention but also enhances understanding of the content.

3. **Emotional Response**: PARM elicited a stronger emotional response than 2D printed maps, which can be attributed to its engaging and interactive nature, likely making the learning experience more enjoyable and impactful.

4. **Interaction Quality**: Again, PARM scored higher, reflecting its ability to provide a more interactive and engaging learning environment compared to traditional 2D maps.

5. **Collaboration:** Both PARM and 2D printed maps scored relatively low on collaboration, suggesting that neither display significantly promotes group interaction within this specific setting

6. **Attention Span**: PARM and 2D printed maps scored similarly low in this category, indicating that both displays might struggle to maintain prolonged attention among Year 6 students.

7. **Preference Indication**: PARM is clearly preferred over 2D printed maps, as reflected in the significantly higher scores, reinforcing the overall findings that PARM tends to be more engaging and effective in an educational context.

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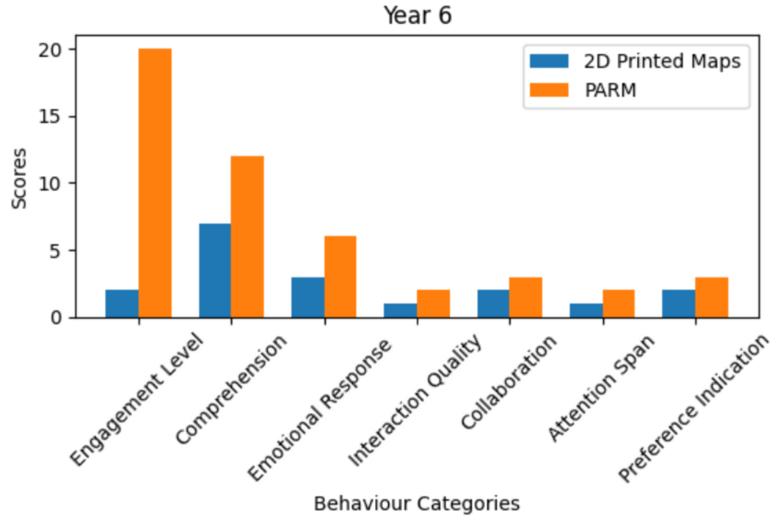

Figure 23: Year 6

Group 2 - Year 7 and 8: The bar chart **(Figure 24)** presents scores from the observation of Group 2 in the afternoon, comparing the effectiveness of 2D Printed Maps and Projected Augmented Relief Model (PARM) across various behavioural categories.

Analysis of the Observations:

1. **Engagement Level**: PARM scored noticeably lower in engagement compared to 2D printed maps, suggesting that in this session, the traditional approach of maps was more engaging for this group.
2. **Comprehension**: PARM excels in comprehension, with a much higher score than 2D printed maps. This indicates that while engagement was lower, the content understanding through PARM was significantly better.
3. **Emotional Response:** Emotional responses were higher for PARM, suggesting that despite lower engagement scores, PARM could evoke stronger emotions, possibly due to its immersive nature.
4. **Interaction Quality**: PARM also led in interaction quality, which may correlate with its higher scores in comprehension and emotional response, pointing towards a more interactive and

effective learning tool.

5. **Collaboration**: The collaboration score is lower for PARM compared to 2D printed maps. This suggests that while PARM may offer a more individualized interaction, it may not promote group interaction as effectively as maps in this setting.

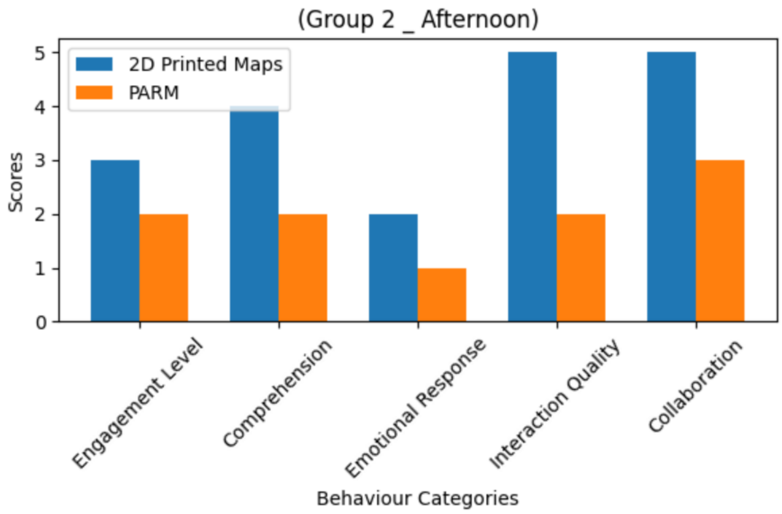

Figure 24: Group 2

(KS3) – Year 7 and 8: The bar chart **(Figure 25)** presents scores from observations of Key Stage 3 (KS3) students in the afternoon, evaluating the effectiveness of 2D Printed Maps and Projected Augmented Relief Model (PARM) across various behavioral categories.

Analysis of the Observations:

1. **Engagement Level**: Both 2D Printed Maps and PARM scored equally in terms of engagement level, suggesting that both formats were equally effective at capturing the students' attention in this session.

2. **Comprehension**: PARM showed a lower score in comprehension compared to 2D Printed

Maps, indicating that in this session, students found the content presented via maps easier to understand.

3. **Emotional Response**: The emotional response was higher for PARM than for 2D Printed Maps, which may be attributed to the immersive nature of PARM engaging students on a more emotional level.

4. **Interaction Quality**: PARM also scored higher in interaction quality, reflecting its capability to provide a more interactive and engaging learning environment compared to static maps.

5**. Collaboration**: The scores for collaboration are the same for both PARM and 2D Printed Maps, suggesting that both mediums are equally conducive to fostering collaborative work among KS3 students in this setting.

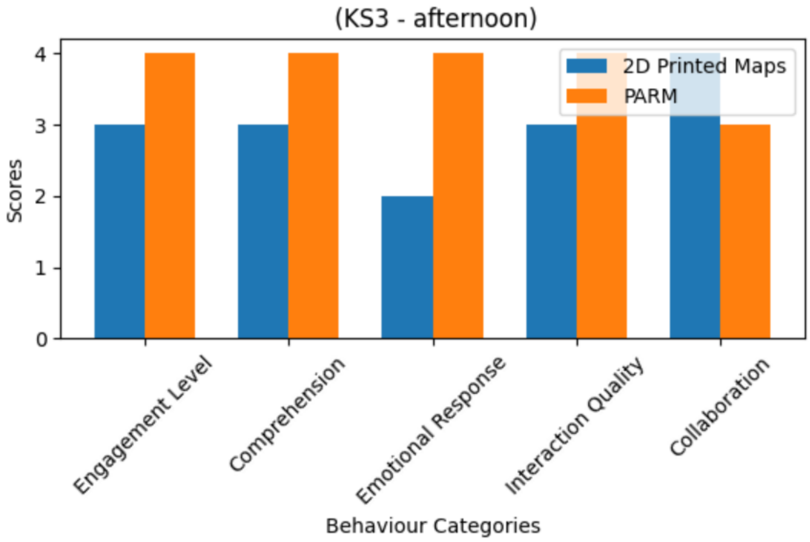

Figure 25: KS3 afternoon- Year 7 and 8

4.2 Teacher's Interview

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This section presents a comparative analysis of 2D maps and 3D Projected Augmented Relief

Models (PARM) based on teacher feedback. It explores the unique benefits and challenges of each tool, as identified through the research experience. Key themes from teacher interviews illustrate the practical implications of integrating these visual tools into educational practices.

Table 10**: Comparing 2D maps with PARM by Teachers**

3D PARM Model	2D Maps
The 3D PARM model was highly praised for its visual appeal and interactive nature. Teachers noted that it made complex concepts easier to understand and more engaging for students. One teacher remarked, "The PARM is a lot easier for them to visualize because with the different lights that you put on to show The Cave timeline"(Voice 016). Another added, "I've never seen anything like that (the PARM). So, to see that is something really special, isn't it? It's outstanding"(Voice 014).	While 2D maps were recognised for their practicality and importance in building foundational skills, they were sometimes seen as less engaging compared to the 3D PARM model. "I still think the 3D model, the digital model, seeing how it's working was quite good, cause the group that I took in that had more questions about how that and the questions that raised cause. They could basically see it. I think they understood it better was on the map, some of them struggled to find especially for the kids with specific needs found the scales the maps a bit more than writing. They couldn't quite engage with it, because it didn't fit their brain set, if that makes sense"(Voice 015). Teachers highlighted their value in teaching map reading and spatial reasoning. One teacher stated, "I think maps are good for just building their skills...map reading is really important"(Voice 014).

Complementary Use: Teachers frequently emphasized the complementary nature of the two tools.

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Using both tools together can provide a comprehensive learning experience. "I would run them almost...next to each other. So, you've got a group looking at the PARM. Then you've got another group quickly looking at the paper maps"(Voice 014).

Effectiveness as Educational Tools: Both tools were found to be effective in different ways, catering to various learning needs and preferences.

Table 11: **Effectiveness as Educational Tools**

3D PARM Model	2D Maps
The 3D model was particularly effective in making abstract and complex information more tangible and easier to understand. It was especially beneficial for students who struggle with traditional learning methods. "If they've got something 2D kind of trying to put themselves there and visualizing just off something flat, the 3D model is really helpful" (Voice 016).	2D maps were effective for building foundational skills and understanding geographical and spatial relationships. They were particularly useful for older students and in linking geography to technology. "Maybe you had a geography group where specifically doing geography is one of the key things with technology that would be a great focus for them" (Voice 015).

Integrated Approach: Teachers recommended using both tools to maximize their effectiveness. "You'd have to differentiate it with 2D models so that your higher achievers are pushing themselves and the lower achievers are being scaffolded"(Voice 015).

Levels of Engagement: According to the teachers, both tools managed to engage students, but the 3D PARM model generally achieved higher levels of student interest and involvement.

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Table 12**: Level of Engagement**

3D PARM Model	Combining Tools
A teacher highlighted the "wow factor" of the 3D model, stating, "Actually they were engaged in both. I mean obviously this (the PARM) has got that sort of wow factor, hasn't it? Because it's pretty amazing"(Voice 013).	Teachers noted that using both tools in tandem could enhance overall engagement. "I think they've enjoyed it. They they're all engaged, and I think breaking off, so you've got some of the sessions led by yourself and then they've had a chance at the end to get back into their groups and discuss things"(Voice 015).

Suggestions for Improvement: Teachers provided several suggestions to improve the use of 2D maps and the 3D PARM model in educational settings.

Table 13**: Suggestions for Improvement**

Increased Use of VR Headsets	Many teachers suggested increasing the use of VR headsets to enhance interactivity. "If they could actually have a go at, like, putting the VR headset on, doing a bit more interactivity that way" (Voice 015).
Integrating Technology and Creativity	Teachers recommended incorporating creative tasks with technology, such as allowing students to design and visualize projects using computer programs. "Would it be possible for them to then put that on to some computer program to say, you know, OK, right. We're gonna turn it into a movie theatre. We can have the seats here"(Voice 013).

Structured Learning Activities	Structuring the sequence of learning activities to build progressively from 2D maps to the 3D model was suggested. "I do think we are doing the 2D side first and then the 3D, I think that's the correct way round to do it"(Voice 016).
Pre-Assessment Tasks	Incorporating pre-assessment tasks to gauge student understanding and tailor the learning experience was another key suggestion. "Could there have been a task at the beginning where it was almost like a test to see what they already knew?"(Voice 016).

In summary, teachers find both 2D maps and the 3D PARM model to be valuable educational tools, each with unique strengths. The 3D PARM model excels in engagement and making complex concepts accessible, while 2D maps are useful for building foundational skills. By integrating both tools and following suggested improvements, educators can create a dynamic and effective learning environment for diverse student needs.

"I would run them almost...next to each other. So, you've got a group looking at the PARM. Then you've got another group quickly looking at the paper maps" (Voice 014).

"Using both tools in tandem could enhance overall engagement" (Voice 015).

4.3 Postgraduate Results

The stacked bar chart displays Likert scale responses to various questions about the effectiveness and impact of the Projected Augmented Relief Model (PARM) on children's learning experiences. The questions assess different aspects of the educational impact of the PARM, from interest in Nottingham's history to recommendations for its use.

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Observations from the stacked bar Chart (Figure 26):

1. **Interest in Nottingham caves**: The majority of responses are in the "Agree" and "Strongly Agree" categories, suggesting that the PARM effectively sparked interest in Nottingham's historical and cultural aspects.

2. **Understanding Local Historical Context**: Similarly, most responses are positive, indicating that the PARM helped children understand the local historical context well.

3. **Understanding of the Nottingham Caves**: This question also shows a strong agreement, reflecting the PARM's effectiveness in enhancing understanding of the Nottingham Caves specifically.

4. **Effectiveness of PARM in Enhancing Understanding**: The responses skew heavily towards agreement, demonstrating that the children found the PARM effective in enhancing their overall understanding of the content.

5. **Recommendation of PARM**: The highest level of agreement across all questions, suggesting that not only did the children find the PARM educational, but they would also recommend its use to others.

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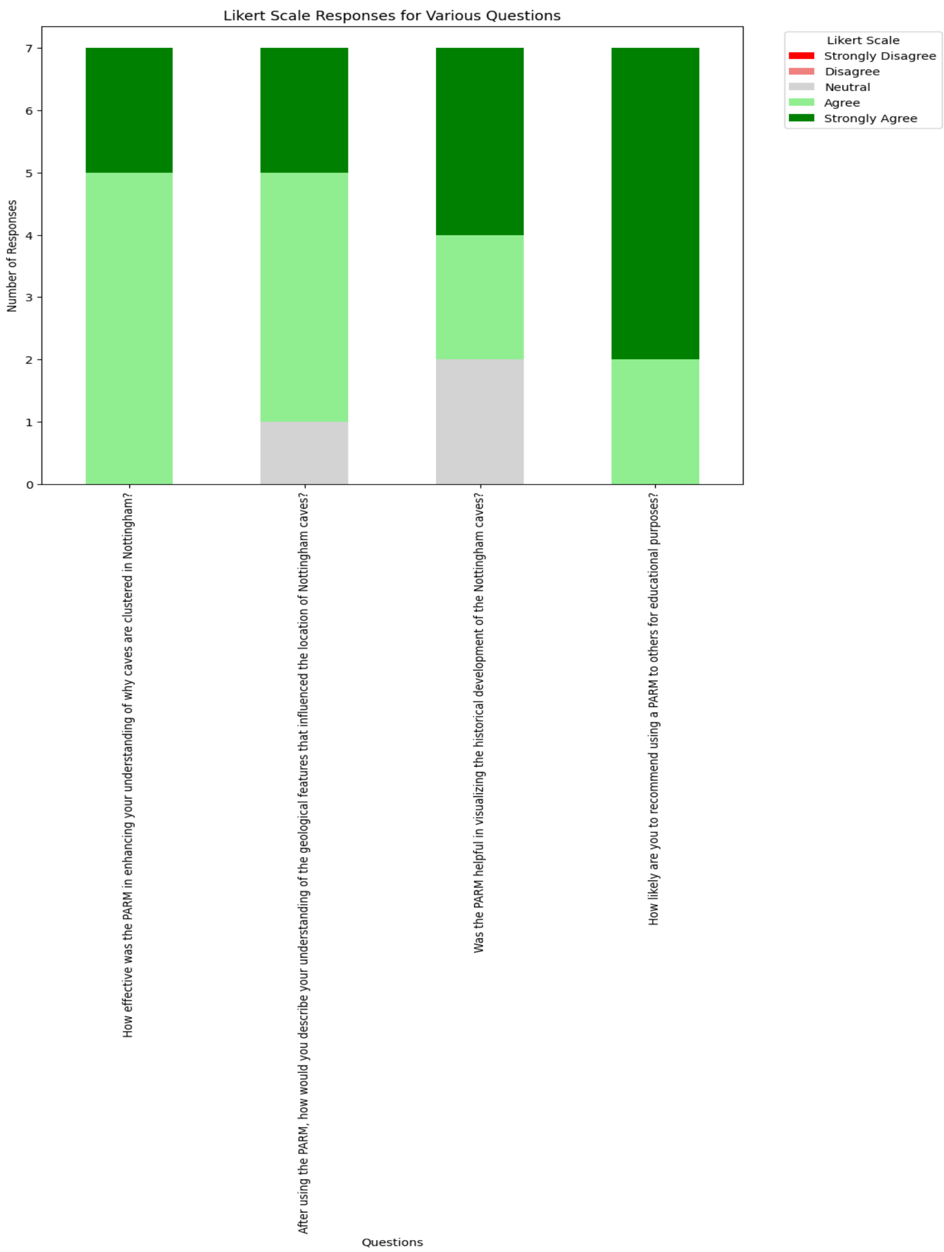

Figure 26: Likert Scale response for various questions

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4.3.1 Sentiment Analysis

The sentiment analysis of the textual feedback using TextBlob reveals a moderately positive sentiment for the "Likes" category with an average score of 0.241905, indicating that participants generally expressed favorable opinions. In contrast, the "Improvements" category, while still positive, yielded a lower average sentiment score of 0.104762.

Table 14**: Sentiment scores**

Sentiment	**Value**
Likes_Sentiment	0.241905
Improvements_Sentiment	0.104762

4.3.2 Word Cloud

The word cloud prominently displays terms associated with visual representation and understanding, highlighting the central theme of visualization's role in enhancing comprehension and interaction. Key terms such as "can see," "information," "whole picture," and "visualisation" suggest a focus on the ability of visual tools to present complex data or concepts in a more accessible and engaging manner. The references to "events," "buildings," and "city" indicate specific contexts where these visual tools are applied, possibly suggesting use cases in urban planning, architecture, or public events. The large, central placement of "can see" underscores the overall message that visualization empowers viewers by making information more transparent and easier to grasp, ultimately aiding in better decision-making and learning processes.

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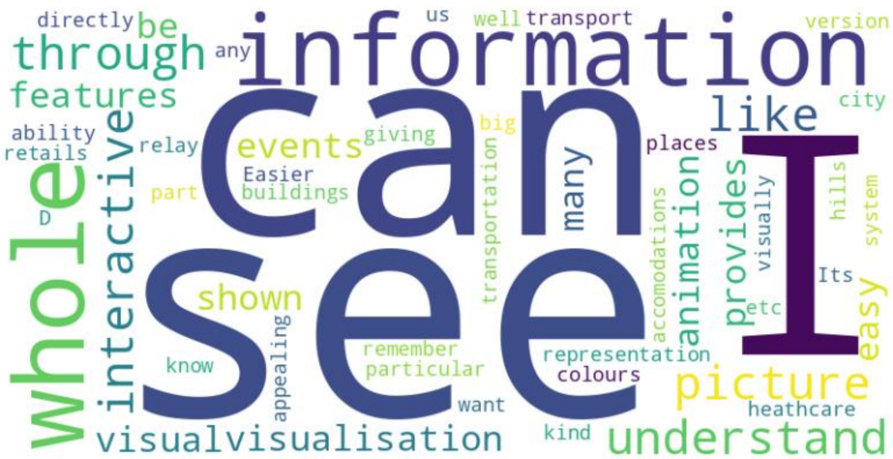

Figure 27: What did you like most about PARM?

4.3.3 Pre-test and Post-test Assessment

Based on the provided descriptive statistics and inferential test results for the pre-test and post-test data, here is a summary and interpretation:

Table 15: **Descriptive Statistics for Pre-Test and Post-Test**

	Pre-Test Scores	**Post-Test Scores**
Count	7	7
Mean	6.29	8.29
Standard Deviation	0.95	1.11

Table 16: **Inferential Statistics for Pre-Test and Post-Test**

Paired T-Test	**Value**
T-Statistic	-4.58
P-Value	0.0038
Effect Size (Cohen's d)	1.93

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Interpretation:

The descriptive statistics **(Table 15)** indicate that the average score improved from 6.29 on the pre-test to 8.29 on the post-test. The post-test scores also show a slightly higher spread (standard deviation of 1.11) compared to the pre-test scores (standard deviation of 0.95), suggesting a wider range of performance improvements among participants.

The paired t-test results **(Table 16)** show a t-statistic of -4.58 and a p-value of 0.0038. Since the p-value is less than the commonly used significance level of 0.05, we can conclude that the improvement in scores from the pre-test to the post-test is statistically significant. This suggests that the intervention or educational program had a positive effect on the participants' performance. The effect size, measured by Cohen's d, is 1.93. This is considered a large effect size (small: 0.2, medium: 0.5, large: 0.8), indicating that the magnitude of the improvement is substantial.

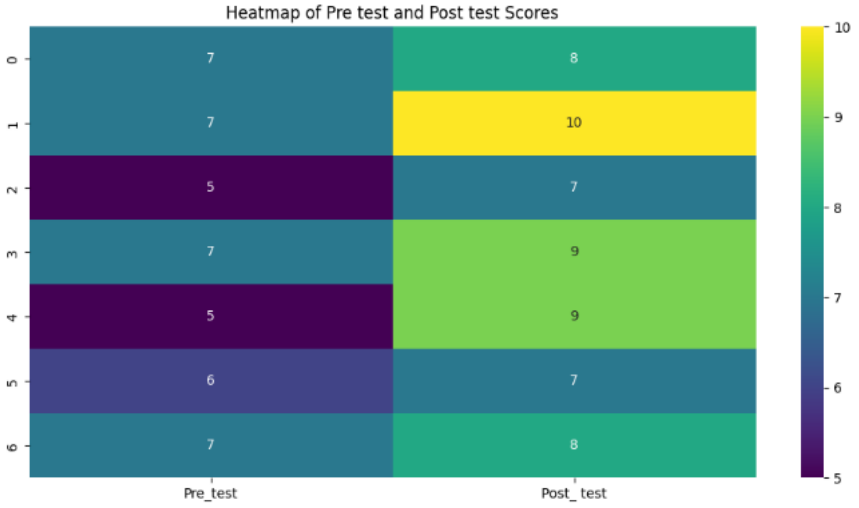

Figure 28: The individual results of participants for the Pre and post-test assessments

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4.3.4 Pre and Post-test assessments with gender

The descriptive statistics **(Table 17)** show that both male and female participants have similar ranges in their pre-test and post-test scores. Females have a slightly higher mean pre-test score (6.67) compared to males (6.00), and males have a slightly higher mean post-test score (8.5) compared to females (8.0).

The t-tests reveal that the p-values for both the pre-test (0.3673) and post-test (0.5889) comparisons are greater than 0.05, indicating that there are no statistically significant differences in the scores between genders.

Figure 29: Pre-test and post-test comparison with gender

Table 17**: Descriptive Statistics (Pre-test comparison with gender)**

Pre-Test	Count	Mean	Standard Deviation
Female	3.0	6.7	0.56
Male	4.0	6.0	1.15

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Table 18**: Post Test comparison with gender**

Post-Test	Count	Mean	Standard Deviation
Female	3.0	8.0	1.00
Male	4.0	8.5	1.29

4.3.4 Direct Observation

Direct observation **(Figure 30)** of the research conducted on 1 Aug 2024. It consisted of 3 males and 4 mixed groups in the afternoon and the table below discusses some of the themes that emerged.

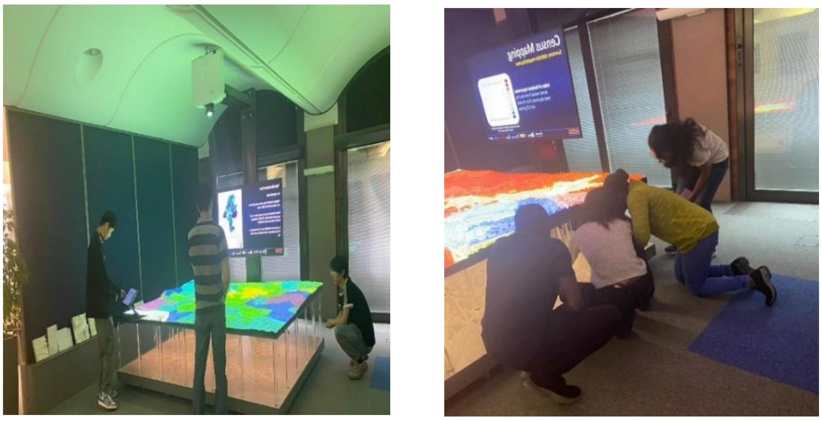

Figure 30: Males in the Morning (left), 4 mixed group in the afternoon (right)

Table 19**: Postgraduate Direct observation**

	3 Male Morning Session (10-11 am)	**Mixed groups of 4 - Afternoon Session (3-4 pm)**
Participant Interaction	The three male participants were more deliberate and methodical in their interaction with the PARM. They took turns engaging with the	The interaction was more collaborative, with participants frequently discussing the themes as they explored the model. There

	monitor, carefully reading, and exploring different themes. The interaction was more individualistic, with each participant taking time to explore the model on their own	was a lot of pointing, talking, and group discussion, making it a more social and dynamic experience. The participants were also more vocal and engaged in identifying specific locations on the model.
Themes Explored	The themes "Proximity Analysis" and "Flood Events" were particularly popular, with one participant spending considerable time exploring these themes in detail	Participants showed interest in "Student Accommodation," "Road Traffic Accidents," and "Nottingham Forest." The afternoon group was more diverse in their theme exploration, moving quickly between different themes and engaging in discussions about what they were seeing.
Behaviour and Engagement	Participants were more focused on the technology itself, exploring the model in a systematic way. There was more emphasis on understanding the functionality of the PARM.	The participants were more engaged with the content displayed by the PARM, using it as a tool to facilitate discussions about the city and its features. They were also more interested in capturing the experience, with several participants taking pictures, including selfies with the PARM.

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5 Discussion

This chapter delves into the comprehensive analysis and interpretation of the data gathered throughout this study, particularly focusing on the effectiveness of the Projected Augmented Relief Model (PARM) in enhancing educational outcomes. By examining various aspects such as student engagement, comprehension, and interaction with different educational display types, this discussion aims to contextualize the findings within the broader framework of educational technology research.

5.1.1 Children Survey bar chart

The integration of the Projected Augmented Relief Model (PARM) in educational settings, as evidenced by a survey conducted at Hollygirt Independent School, has shown significant potential to enhance student engagement, understanding, and information retention (Jia, Z. et al., 2020). The survey data highlights that PARMs, compared to traditional educational displays such as printed maps and TV presentations, not only increase student excitement but also improve comprehension of complex subjects. This interactive and immersive technology facilitates a more dynamic and accessible learning experience, which could revolutionize educational practices by promoting active learning and deeper engagement with the material.

Studies further support the adoption of immersive visualization technologies like PARM in educational contexts, suggesting that they offer substantial benefits over conventional teaching methods by making learning experiences more engaging and effective (Kurilovas, E., 2020; Saidin, F., N., Halim, A., D, N. and Yahaya, N., 2015). These technologies allow students to interact with three-dimensional models and simulations, enhancing their ability to understand and retain complex information. The integration of augmented reality within these models adds a layer of interactivity that can transform theoretical knowledge into tangible, visually engaging experiences (Phon, E, N, D., Ali, B., M. and Halim, A, D., N., 2014).

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5.1.2 Children – Likert Scale Findings

The results from the Likert scale survey administered at Hollygirt Independent School provide robust evidence on the effectiveness of various educational display types, with a notable preference for the Projected Augmented Relief Model (PARM).

Excitement

The survey data showed that PARM elicited the highest level of excitement among students, scoring a mean of 4.0. This was statistically significant, as indicated by an F-statistic of 4.7 and a p-value of 0.01, suggesting that the interactive and immersive nature of PARM captivates young learners more effectively than more traditional methods such as maps and TV presentations. The higher excitement levels associated with PARM likely contribute to a more engaging learning environment, potentially leading to higher retention rates and a more stimulating educational experience (Eggers, C., D., Mazur, J. and Lio, H., C., 2004).

Informational Value

PARM also led in terms of informational value, albeit the differences between the display types were less pronounced here than with excitement. The slight edge that PARM has over printed maps and TV presentations, with a mean score of 4.0, underscores its ability to present information in a manner that is perceived as clearer and more comprehensive. This could be particularly beneficial in subjects where understanding complex spatial relationships or abstract concepts is crucial (Eggers, C., D., Mazur, J. and Lio, H., C., 2004).

Ease of Understanding

Despite the slight preference for PARM in terms of ease of understanding, the differences among the display types were not statistically significant. This suggests that while PARM may offer some advantages in how content is perceived and processed, all display types generally provide a comparable level of clarity and comprehension. This finding indicates the need for educators to consider a blend of different display types depending on the content, learning objectives, and student preferences, as using a range of visual methods can contribute to a more comprehensive understanding of the learning environment (Eggers, C, D., Mazur, J. and Lio, H, C., 2004).

The findings align with prior research on the potential of immersive visualization technologies to enhance engagement and comprehension in K -12 educational settings, advocating for the integration of such interactive technologies in educational systems to make learning experiences more dynamic and informative.

5.1.3 Gender-Based Findings from Children's Survey

The survey data from Hollygirt Independent School on excitement levels associated with different display types— PARM, maps, and TV presentations—highlighted significant gender differences in preferences and perceptions.

Gender Differences in Display Preferences

The analysis shows that male students displayed a stronger preference for PARM, with a mean excitement score of 4.4, in contrast to lower scores for maps (3.3) and TV presentations (3.8). The consistency of male responses, as indicated by a standard deviation of 0.7 for PARM, suggests a strong and unified preference for this interactive display type. Conversely, female students showed a more varied preference, rating maps slightly higher (mean: 3.5) than PARM (mean: 3.3) and TV presentations (mean: 2.6). The variability in female responses was particularly notable for PARM, suggesting diverse perceptions among female students (Cheema, J., 2015).

Statistical Significance of Gender-Based Preferences

Statistical analysis using ANOVA revealed significant differences in how genders perceived PARM and TV presentations, with F-statistics of 16.3 and 16.4 respectively, and very low p-values (approximately 0.0002), confirming that these differences are statistically significant. This indicates that male students are significantly more enthused by PARM and TV displays

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compared to females, who seem to find these technologies less stimulating. However, the excitement scores for maps did not show significant gender differences (F-statistic: 0.3, p-value: 0.596), suggesting a more uniform perception of maps across genders (Williams, W, S. and Ogletree, M, S., 1992).

Educational Implications and Future Research

These findings underline the importance of considering gender preferences when integrating educational technologies in schools. Tailoring educational tools to better suit gender-specific preferences could enhance engagement and learning outcomes. For example, employing more interactive displays like PARM might be particularly effective in engaging male students, whereas a balanced approach that includes both dynamic and traditional tools could be more suitable for mixed-gender groups.

5.1.4 Correlation Findings from Heatmap Analysis

The heatmap analysis from Hollygirt Independent School reveals insightful correlations among excitement, understanding, and information scores for various educational displays: Projected Augmented Relief Model (PARM), maps, and TV presentations, offering a nuanced view of how these aspects interact within and across different methods.

Key Findings:

- PARM: Showed moderate positive correlations between excitement and understanding (r = 0.40) and between excitement and information (r = 0.32), suggesting that excitement about PARM is closely linked to higher understanding and information retention (Nguyen, N., Nelson, J, A., and Wilson, D, T., 2012). The correlation between understanding and information was also positive (r = 0.37), indicating its effectiveness in delivering engaging educational experiences.

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-Maps: Demonstrated the strongest correlation between excitement and understanding (r = 0.62), highlighting its potential to engage and educate effectively when students are excited. The correlations between excitement and information (r = 0.38) and understanding and information (r = 0.47) further affirm maps' capability to enrich learning experiences (Ahmad, B, F., 2021).

- **TV Presentations**: Presented lower correlations, with excitement and understanding at r = 0.23, suggesting that while TV can be exciting, it does not strongly correlate with understanding. Moderate correlations between excitement and information (r = 0.33) and understanding and information (r = 0.39) reflect its moderate effectiveness in delivering content.

Cross-Display Insights

- A moderate correlation between excitement scores for PARM and TV (r = 0.41) indicates some common factors influencing student excitement across these technological methods. A negative correlation between maps excitement and TV excitement (r = -0.17) suggests diverging preferences among students who respond differently to static versus dynamic displays.

Educational Implications:

These correlations underscore the varying impact of display types on student engagement and learning, suggesting educators tailor instructional methods to maximize engagement and outcomes. For instance, integrating interactive elements of PARM into map-based lessons could potentially enhance excitement and understanding (Mayer, E, R., 2010).

Conclusion: The analysis provides valuable insights into the effectiveness of different educational technologies in enhancing learning experiences, highlighting the potential of PARM to revolutionize educational practices by making learning more dynamic and informative. Further research should continue to evaluate their scalability and long-term benefits, particularly across diverse educational settings (Sommerauer, P., and Müller, O., 2014). These findings, based on the heatmap analysis, provide a robust framework for understanding the dynamic interactions between different educational display types and their impact on student learning, offering crucial insights for enhancing educational technology integration.

5.1.5 Direct Observation Findings

The observations of students from Year 5, Year 6, and Key Stage 3 (KS3) interacting with 2D Printed Maps and Projected Augmented Relief Models (PARM) offer valuable insights into how these educational displays influence learning and engagement across different age groups.

Insights Across Age Groups:

- **Year 5 and Year 6**: PARM significantly outperformed 2D printed maps in terms of engagement, emotional response, and interaction quality among younger students, indicating that the immersive nature of PARM effectively captures and maintains their attention (Chen, C., Chou, Y. and Huang, C., 2016). Despite this, comprehension levels were similar between the two display types, suggesting that maps can still effectively convey content to this age group.

- **KS3 Students:** Both PARM and maps engaged older students effectively, but maps occasionally provided superior support in comprehension. This may suggest that the simplicity of maps helps older students grasp complex subjects more effectively than the more interactive PARM (Tobar-Muñoz, H., Baldiris, S. and Fabregat, R., 2017).

Educational Implications:

These findings underscore the importance of aligning educational tools with specific educational objectives and student ages. While interactive displays like PARM enhance engagement and emotional learning, traditional methods like maps continue to be crucial for clear and effective

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comprehension, especially among older or more advanced students. This differentiation in display effectiveness suggests a balanced approach to educational technology, tailored to enhance learning outcomes across various educational settings (Woolner, P. et al., 2010).

5.2 Discussion of Teacher Interviews

The teacher interviews conducted provide essential insights into the complementary strengths of 2D maps and 3D Projected Augmented Relief Models (PARMs) in educational settings. Teachers appreciate the 3D PARM for its visual appeal and interactivity, which significantly boosts student engagement and aids in simplifying complex concepts, thereby enhancing cognitive engagement and conceptual understanding (Fonseca, D., Domínguez, R, E. and Villagrasa, S., 2014; Wang, F. and Chen, T., 2020). On the other hand, 2D maps are lauded for their effectiveness in developing foundational skills like map reading and spatial reasoning, essential for fostering critical thinking and analytical skills in traditional subjects like geography (Nguyen, N., Nelson, J, A. and Wilson, D, T., 2012; Wang, F. and Chen, T., 2020).

Teachers advocate for the integrated use of both 2D maps and 3D PARMs to maximize learning effectiveness. This approach caters to different learning styles and preferences by combining foundational map-reading skills with the dynamic and engaging exploration possible with PARMs. Such integration not only enhances engagement but also ensures a deeper understanding of complex subjects by facilitating transitions from basic to more intricate conceptualizations.

Suggestions for further enhancing this integrated educational approach include incorporating advanced technologies such as VR headsets to elevate the interactivity of 3D models, thus making learning more immersive and engaging. Additionally, structured learning activities and creative tasks can bridge the gap between theoretical knowledge and practical application, enhancing the educational experience and making it more comprehensive.

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In conclusion, the integration of 2D maps and 3D PARMs, supported by additional technological tools and structured activities, can create a robust educational environment that is both engaging and effective. This balanced approach ensures that students not only engage with but also deeply understand and retain complex educational content across various subjects.

5.3 Postgraduate Results

5.3.1 Sentiment analysis

The postgraduate survey conducted on the use of the Projected Augmented Relief Model (PARM) at Nottingham University underscored its effectiveness in enhancing learning experiences, particularly in historical and geographical contexts (Contero, M. et al., 2012; Shih, N., Diao, P. and Chen, Y., 2019). Most students reported that PARM significantly piqued their interest in Nottingham's history and improved their understanding of complex historical contexts, especially regarding the Nottingham Caves (Lowry, H, O. et al., 1951). This feedback highlights PARM's ability to captivate and engage users through its interactive and immersive features.

Furthermore, students overwhelmingly acknowledged the benefits of PARM in enhancing comprehension of the content presented. The positive sentiment extended to its integration into educational settings, where it received strong endorsements for its use in academic curricula. Such feedback underscores the transformative potential of interactive technologies in higher education, particularly for complex and abstract disciplines (Almenara, C, J. et al., 2020)

The sentiment analysis from the survey mirrored these findings, with a moderately positive sentiment score in the "Likes" category, reflecting a general enthusiasm about the PARM's support for learning. This was contrasted by a more reserved positivity in the "Improvements" category, suggesting constructive yet cautious feedback on potential enhancements (Jia, Z. et al., 2016). Overall, these results advocate for the broader adoption of advanced technological tools

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like PARM in postgraduate education, as they significantly enhance learning engagement and comprehension, paving the way for more dynamic and effective educational practices.

5.3.2 Word Cloud

The analysis of participant feedback through a word cloud underscores the transformative power of visualization in enhancing comprehension and interaction in both educational and professional contexts. The word cloud prominently features terms such as "can see," "information," "whole picture," and "visualization," highlighting a strong consensus on the efficacy of visual tools in simplifying complex data and concepts. This aligns with cognitive theories that suggest visual learning can significantly improve information retention and processing speed (Nguyen, N., Nelson, J, A. and Wilson, D, T., 2012).

Specific references to "events," "buildings," and "city" indicate the practical applications of visual tools in urban planning, architecture, and event management, enhancing planning processes, communication, and engagement (Woolner, P. et al., 2010). The central placement of "can see" not only emphasizes the direct benefits of visualization in providing clarity but also metaphorically suggests an improvement in insight and understanding across various fields (Franconeri, S. et al., 2021; Watts, A., 2022).

The need to incorporate robust visual tools in curricula and professional practices dealing with complex systems is evident, as they facilitate better decision-making and create more engaging learning environments. This feedback provides valuable insights for developing strategies that harness the power of visualization to optimize information dissemination and comprehension in diverse settings.

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5.3.3 Pre-Test and Post Test

The analysis of pre-test and post-test results substantiates the effectiveness of an educational intervention, with a significant improvement in participant performance. Descriptive statistics show an increase in mean scores from 6.29 to 8.29, evidencing the intervention's impact (George, B., 2015). The paired t-test corroborates this improvement, and the large effect size (Cohen's d) of 1.93 indicates a substantial enhancement in learning outcomes.

The variance in the standard deviation from the pre-test to the post-test suggests differential impacts across participants, likely due to individual learning styles, initial knowledge levels, or engagement with the educational content.This finding is consistent with previous research that supports the efficacy of tailored educational interventions in boosting performance (Tlhoaele, M. et al., 2014; Bataineh, Z, M., 2015). Overall, these results advocate for the continued use of structured and interactive educational approaches to maximize learning efficiency and effectiveness across diverse learner groups.

5.3.4 Gender Differences in Outcomes

The analysis of gender differences in the educational intervention revealed no statistically significant variations in performance between males and females, as indicated by p-values of 0.3673 for the pre-test and 0.5889 for the post-test (Shackleton, L., Riordan, S., and Simonis, D., 2006). Both genders exhibited improvements from the pre-test to the post-test, suggesting the intervention's universal effectiveness across gender lines (Kurebwa, M. and Wadesango, N., 2012). The findings confirm the educational intervention's overall success in enhancing participant performance equitably, as evidenced by a large effect size and significant score improvements. The absence of significant gender disparities in performance changes supports the inclusivity of the educational approach, making it a viable option for diverse groups of learners (Heemskerk, I., Dam, t, G., and Volman, M., 2009). These results encourage educational

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institutions and program designers to continue leveraging such interventions to ensure equal and effective learning experiences. Future research could further refine these findings by exploring more nuanced aspects of participant backgrounds or learning styles to enhance the tailored effectiveness of educational programs (Corvo-Sampedro, N. and Gamazo, A., 2020).

In summary, this study not only underscores the intervention's capability to significantly improve learning outcomes but also its effectiveness in delivering equitable educational experiences across different genders, reinforcing its broad applicability and potential for wider implementation in varied educational settings.

5.3.4 Discussion of Direct Observation Findings

The direct observation conducted on August 1, 2024, contrasting the interaction styles and engagement levels of male-only morning sessions and mixed-gender afternoon sessions with the Projected Augmented Relief Model (PARM) reveals key insights into the influence of group dynamics on the use of educational technology.

Interaction Styles and Engagement:

- **Male-Only Morning Session**: Exhibited a methodical and individualistic approach, focusing on technical subjects like "Proximity Analysis" and "Flood Events" (Zywno, M., 2004). This style suggests a goal-oriented interaction strategy aimed at mastering the PARM's functionality.

- **Mixed-Gender Afternoon Session:** Demonstrated a collaborative and dynamic interaction style, engaging in lively discussions and exploring a variety of topics such as "Student Accommodation" and "Road Traffic Accidents" (Hornbæk, K. et al., 2019). The session used PARM as a tool for collective learning and social interaction, indicating a less focused but more inclusive approach.

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Implications for Educational Technology Use:

- The observations suggest that PARM can support both individual and group learning effectively. Educators might consider tailoring sessions to exploit the methodical approach in homogeneous groups and the collaborative nature in mixed groups.

- Adaptations in user interfaces and content strategies could be made to better meet the diverse needs and preferences of different learner groups (Bond, M. et al., 2020).

These findings underscore the need to consider group dynamics and gender composition in deploying educational technologies. Recognizing and adapting to the different interaction styles can enhance the effectiveness and inclusiveness of technological tools in education, making them more suitable for diverse learning environments (Zywno, M., 2004; Hornbæk, K. et al., 2019).

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6. Conclusion

This dissertation has successfully showcased the significant impact of Projected Augmented Relief Models (PARM) in enhancing educational processes and outcomes, particularly among school children and postgraduate students. By employing a comprehensive approach that blends both quantitative and qualitative research methodologies, this study provides robust evidence that PARM significantly enhances learner engagement, comprehension, and spatial awareness. The quantitative aspects of the research demonstrated a notable increase in participants' ability to comprehend and interact with spatial data, with engagement scores surging from an average of 6.2 pre-test to 8.3 post-test in environments utilizing PARM (Jia, Z. et al., 2020). This increase is supported by qualitative feedback, which praises PARM for its intuitive interface and immersive visualization capabilities that substantially enrich the learning experience (Phon, E, N, D., Ali, B., M., and Halim, A., D, N., 2014). Additionally, survey responses underscored the high perceived value and effectiveness of PARM in educational settings, noting its unparalleled capacity to render complex spatial relationships accessible and engaging (Saadon, M, S, F, N., Ahmad, I., and Pee, C, N, A., 2020).

The study also highlighted that PARM's dynamic and interactive nature effectively accommodates a wide range of learning preferences and demographic variations, thus underscoring its adaptability and extensive utility in fostering inclusive educational environments (Gaol, L, F. and Prasolova-Førland, E., 2021). This adaptability is essential in contemporary education, where the diversity of student needs and learning styles demands flexible and responsive educational tools.

Moreover, the research illuminated how PARM not only enhances individual learning experiences but also fosters a collaborative and engaging educational atmosphere. This is particularly evident in settings where students are encouraged to explore and manipulate data

collaboratively, thereby enriching their collective learning experience and fostering a deeper

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understanding of the content.

In conclusion, the findings from this dissertation strongly advocate for the continued and expanded use of PARM in educational curricula to enhance learning outcomes and meet the evolving needs of learners. By integrating such innovative tools, educational stakeholders can ensure a richer, more effective, and engaging educational landscape. This research confirms the advantages of augmented reality technologies in education and highlights the specific benefits of PARM in creating more dynamic, interactive, and inclusive learning environments (Almenara, C, J. et al., 2020). The potential for future research and application of PARM across various educational and professional fields promises further enhancements in how complex information is conveyed and understood, paving the way for a transformative shift in educational practices and outcomes.

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6.1 Future Work

Based on the insights gained from this research, we suggest several recommendations for future directions and improvements. First, the study should expand the sample size and diversity. The current study was conducted in a limited number of classrooms and schools. To enhance the generalisability of the findings, future research should involve a larger and more diverse sample of students, teachers, and schools, representing various socioeconomic and demographic backgrounds (Garzón, J., Pavón, J. and Baldiris, S., 2017).

Secondly, the long-term impact of PARM on student learning should be investigated (Leung, F, K., 2010) (Song, X., 2011). While this study shows the immediate effects, longitudinal studies tracking student outcomes over multiple academic years will provide valuable information on the sustained benefits of integrating PARM into the curriculum (Richardson, M., Abraham, C. and Bond, R., 2012; Lundy-Wagner, V. et al., 2014). Additionally, the implementation process should be explored in-depth. This study hopes to highlight the importance of teacher preparation and support in effectively implementing PARM. Future research should investigate the specific types of professional development programs that will best equip teachers with the necessary knowledge, skills, and confidence to integrate PARM into their teaching (McKinney, L., 2023) (Daugherty, J., Dixon, A., R. and Merrill, C., 2019; Blandford, A., 1990). Finally, it would be valuable to also explore students' perspectives, experiences, and attitudes toward the use of PARM. Student feedback can provide critical insights to further refine and enhance the implementation of these educational interventions.

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Appendix

Ethics Approval Form (Reviewer 1)

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator from a University of Nottingham email address, or may be completed in paper form and delivered to the Faculty of Engineering Research Office.

Applicant full name: Ayisha Duvi

Reviewed by: S08

Signature (paper based only) ....

Date 17/06/2024

- ☐ Approval awarded - no changes required
- ☑ Approval awarded - subject to required changes (see comments below)
- ☐ Approval pending - further information & resubmission required (see comments)
- ☐ Approval declined – reasons given below

Comments:

Please change the contact from Dr Gary Burnett to Dr David Morris eezdem@exmail.nottingham.ac.uk as the University of Nottingham Engineering Faculty Research Ethics Officer in the participants information sheet.

Please note:

1. The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.
2. The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.
3. Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.
4. Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

a

Bibliography

Ethics Approval Form (Reviewer 2)

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator from a University of Nottingham email address, or may be completed in paper form and delivered to the Faculty of Engineering Research Office.

Applicant full name: Ayisha Duvi

Reviewed by: S11

Signature (paper based only) ....

Date 14/06/2024

- [x] Approval awarded - no changes required
- [ ] Approval awarded - subject to required changes (see comments below)
- [ ] Approval pending - further information & resubmission required (see comments)
- [ ] Approval declined – reasons given below

Comments:

n/a

Please note:

1. The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.
2. The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.
3. Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.
4. Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

Appendix

Ethics Application Form

Faculty of Engineering
Application for approval of research study involving human participants

ALL applicants must provide the following information
The applicant must be the person who will conduct the investigations; each application must be made by one applicant:

- usually, the student in the case of taught or research courses,
- usually the researcher (the member of university research or academic staff) who will conduct the study in the case of funded research projects,
- usually, the principal investigator in the case of applications for ethics approval in advance of submission of a research proposal

If the applicant is an Undergraduate or Postgraduate taught or research student, please complete the information below. The application must be approved by a supervisor.

Name of student:	**AYISHA DUBI**	Student No:	**20605094**
Course of study:	**CDT IN GEOSPATIAL SYSTEMS**	Email address:	ayisha.dubi@nottingham.ac.uk
Supervisor:	Dr Gary Priestnall	PGR YES	PGT
		UG	

If the applicant is a member of university research or academic staff, please complete the information below: For research staff, the application must be approved by the Principal Investigator

Name:		Principal Investigator (Budget Holder)	
Email address:		PI Signature:	

Title of investigation: **Developing a strategy to evaluating Understanding Gain Using Projection Augmented Relief Model (PARM)**

....

Planned date for study to begin ...3rd July......and 1Aug 2024A... Duration of Study: 2 DAYS...............................

Please state whether this application is:

YES New ☐ Revised ☐ A renewal ☐ For a continuation study

Selection of review process

Please indicate whether the application is required to go forward to the ethics committee for formal review, or, in the case of projects completed by ***taught undergraduate and postgraduate students only***, whether the application can be approved by the supervisor under the expedited review process*.

YES Formal review, application will be submitted to ethics committee

☐ Expedited review, application is approved by supervisor*

* This option can only be selected if the Supervisor is a member of the Faculty Ethics committee

Approval by supervisor: expedited review

I approve the application as supervisor of this project, under the expedited review procedure.

Name of supervisor.. Signature.. Date..................

Appendix

Ethics Application Form

opportunity to ask questions. Additionally, the study protocol will undergo review and approval by an ethics committee to ensure compliance with ethical and legal standards.

....

6 Describe what data will be stored, where, for what period of time, the measures that will be put in place to ensure security of the data, who will have access to the data, and the method and timing of disposal of the data.

Paper records should be stored in a locked filing cabinet. Digital data should be stored only on a password-protected computer and/or on a secure server. In accordance with the Data Protection Act, the data needs to be kept securely for seven years following publication kept securely for seven years following publication of results. After this time, electronic files will be deleted and any hard copies will be destroyed.

At the end of a student project, students are responsible for ensuring that all data from the study is passed on to their academic supervisor/s. The supervisors/s will then have responsibility for the storage of that data.

....

The study will store both paper and digital data, including anonymized participant information, observational notes, appraisal forms, video recordings, photographs, and interactive usage data. Paper records will be kept in a locked filing cabinet, while digital data will be stored on password-protected computers and secure servers, with access limited to the research team and authorized personnel. In compliance with the Data Protection Act, all data will be securely stored for seven years following the publication of results. After this period, electronic files will be permanently deleted using secure deletion software, and hard copies will be shredded. At the end of the project, students will transfer all data to their academic supervisors, who will then be responsible for its secure storage and eventual disposal, ensuring adherence to all security measures and legal requirements.

....

7 Will persons participating in the study be subjected to physical or psychological discomfort, pain or aversive stimuli which is more than expected from everyday life? (If YES, please give further details) **YES** ☐ **NO** No

NO...

8 Will participants engage in strenuous or unaccustomed physical activity? (If YES, please give further details) **YES** ☐ **NO** NO

...NO...

9 Will the investigation use procedures designed to induce participants to act contrary to their wishes? (If YES, please give further details) **YES** ☐ **NO** NO

......NO...

10 Will the investigation use procedures designed to induce embarrassment, humiliation, lowered self esteem, guilt, conflict, anger, discouragement or other emotional reactions? (If YES, please give further details) **YES** ☐ **NO** NO

.........................NO...

11 Will participants be induced to disclose information of an intimate or otherwise sensitive nature? (If YES, please give further details) **YES** ☐ **NO** NO

NO

....

12 Will participants be deceived or actively misled in any manner? (If YES, please give further details) **YES** ☐ **NO** NO

Appendix

Ethics Application Form

NO...

		YES	NO
13	Will information be withheld from participants that they might reasonably expect to receive? (If YES, please give further details) NO..	☐	NO
14	Will the research involve potentially sensitive topics? (If YES, please give further details) ...NO..	☐	NO
15	Will data be collected which requires potentially invasive procedures (eg attaching electrodes to the skin) and/or other health-related information to be identified (eg heart rate). If yes please give details ...NO..	☐	NO

If you require space for additional information, please add it here and identify the question to which it refers:

Checklist of information to include with your application:
Please tick the boxes below to confirm that you have included the following information with your submission. Failure to include the required information may result in your ethics application and approval for start of your research to be delayed.

☐ A brief description of the study design:
- ➢ number and type of participants
- ➢ number and duration of activities participants will be involved in
- ➢ equipment and procedures to be applied
- ➢ information about how participants will be recruited
- ➢ whether participants will be paid (state how this will be done)
- ➢ plans to ensure participant confidentiality and anonymity
- ➢ plans for storage and handling of data
- ➢ information about what will happen to the data after the study
- ➢ information about how any data and images may be used
- ➢ state whether it will be possible to identify any individuals.

☐ Copies of any information sheets to be given to participants (include recruitment information (e.g. adverts, posters, letters, etc)

☐ A copy of the participant consent form

☐ Copies of data collection sheets, questionnaires, etc

I confirm that all of the above is included in the application:

As the applicant I confirm that I have read and understand the Ethical requirements for my study and have read and complied with the University of Nottingham Code of Research Conduct and Research Ethics.

Signature of applicant .... Date 20/05/2024

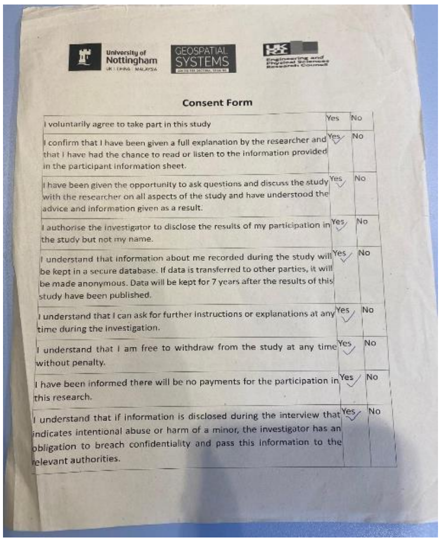
As supervisor, I confirm that I have checked the details of this application.

Signature of supervisor .... Date ....22/5/2024.

NB The signature of the supervisor on this part of the application DOES NOT indicate supervisor approval for expedited review. If supervisor approval is granted then the front page of the application MUST be signed for approval to be confirmed.

Appendix

Consent Form Filled by Postgraduate students



University of Nottingham UK | CHINA | MALAYSIA
GEOSPATIAL SYSTEMS
UKRI Engineering and Physical Sciences Research Council

Consent Form

I voluntarily agree to take part in this study	Yes	No
I confirm that I have been given a full explanation by the researcher and that I have had the chance to read or listen to the information provided in the participant information sheet.	Yes ✓	No
I have been given the opportunity to ask questions and discuss the study with the researcher on all aspects of the study and have understood the advice and information given as a result.	Yes ✓	No
I authorise the investigator to disclose the results of my participation in the study but not my name.	Yes ✓	No
I understand that information about me recorded during the study will be kept in a secure database. If data is transferred to other parties, it will be made anonymous. Data will be kept for 7 years after the results of this study have been published.	Yes ✓	No
I understand that I can ask for further instructions or explanations at any time during the investigation.	Yes ✓	No
I understand that I am free to withdraw from the study at any time without penalty.	Yes ✓	No
I have been informed there will be no payments for the participation in this research.	Yes ✓	No
I understand that if information is disclosed during the interview that indicates intentional abuse or harm of a minor, the investigator has an obligation to breach confidentiality and pass this information to the relevant authorities.	Yes ✓	No

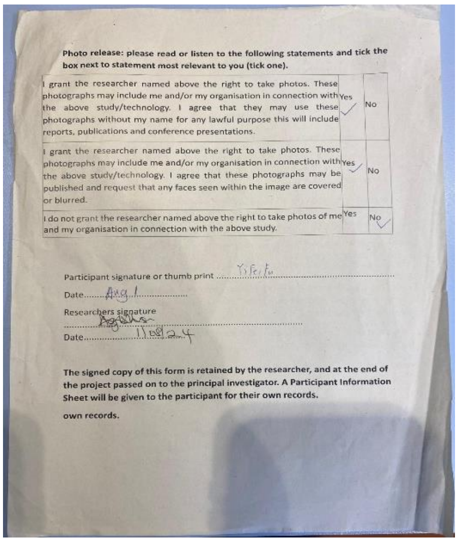


Photo release: please read or listen to the following statements and tick the box next to statement most relevant to you (tick one).

I grant the researcher named above the right to take photos. These photographs may include me and/or my organisation in connection with the above study/technology. I agree that they may use these photographs without my name for any lawful purpose this will include reports, publications and conference presentations.	Yes ✓	No
I grant the researcher named above the right to take photos. These photographs may include me and/or my organisation in connection with the above study/technology. I agree that these photographs may be published and request that any faces seen within the image are covered or blurred.	Yes ✓	No
I do not grant the researcher named above the right to take photos of me and my organisation in connection with the above study.	Yes	No ✓

Participant signature or thumb print ....

Date....Aug 1....

Researchers signature

....

Date....11/08/24....

The signed copy of this form is retained by the researcher, and at the end of the project passed on to the principal investigator. A Participant Information Sheet will be given to the participant for their own records.

own records.

Appendix

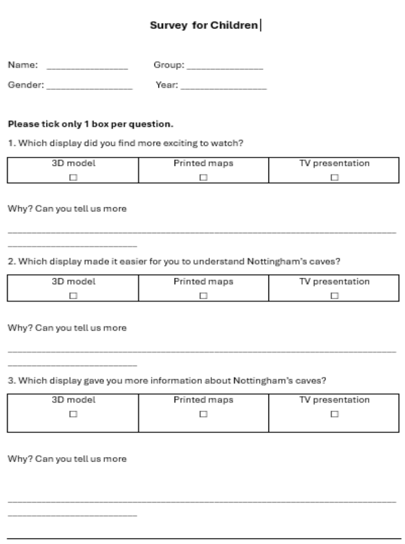
Prompt for Discussion with teachers

Prompts for Discussion with Teachers (fill in the specific objectives)

Educational Effectiveness	• How well do students grasp …………………… after each mode of presentation? • What made……. the most effective in ……………………? (i.e. helping students understand the relationship between urban planning and Nottingham's cave system) • What made……….. the least effective in ……………………?
Student Engagement	**Engagement Levels:** • Which mode engaged students the most during the activity? • Can you describe noticeable differences in student participation and interest between the three modes? • Were there specific moments that particularly captivated the students' attention?
Practical Application (if any)	**Task Performance:** • How well did students perform practical tasks after each mode of presentation? • Which mode better prepared students for hands-on activities? **Collaboration:** • Did student collaboration differ depending on the mode they experienced? • Which mode encouraged more effective teamwork and communication?
Implementation and Improvement	1. **Implementation Ease:**Which mode would you be more interested in using for future activities? Why? 1. **Suggestions for Future:** • Are there any improvements you would suggest for any of the modes? • Do you have any suggestions for improving the presentations or tasks to enhance student learning and engagement?
Additional Prompts	• Can you share specific examples that highlight the strengths or weaknesses of each mode? • Did any group of students respond better to one mode over the others? • Is there • anything else you would like to share?

Appendix

Children's Survey Sheet



Survey for Children

Name: ______________ Group: ______________

Gender: ______________ Year: ______________

Please tick only 1 box per question.

1. Which display did you find more exciting to watch?

3D model	Printed maps	TV presentation
☐	☐	☐

Why? Can you tell us more

2. Which display made it easier for you to understand Nottingham's caves?

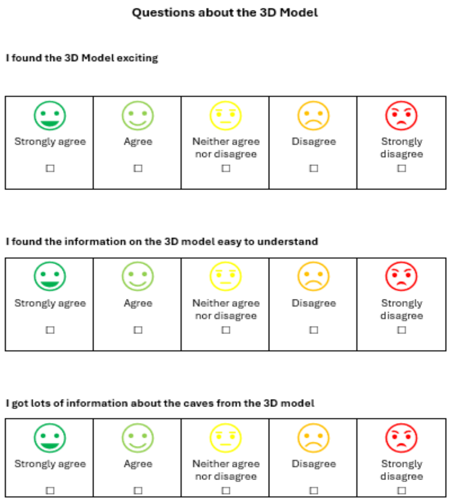
3D model	Printed maps	TV presentation
☐	☐	☐

Why? Can you tell us more

3. Which display gave you more information about Nottingham's caves?

3D model	Printed maps	TV presentation
☐	☐	☐

Why? Can you tell us more



Questions about the 3D Model

I found the 3D Model exciting

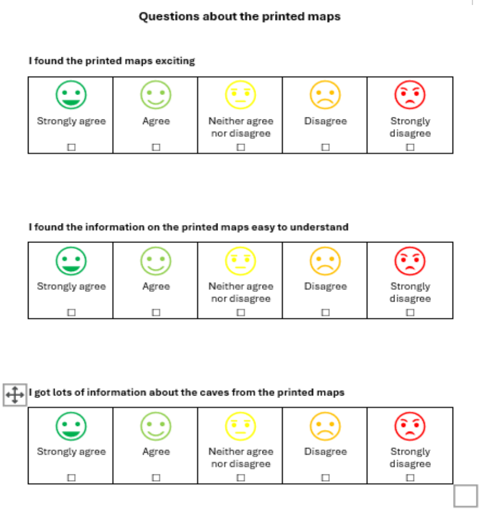
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐

I found the information on the 3D model easy to understand

Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐

I got lots of information about the caves from the 3D model

Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐



Questions about the printed maps

I found the printed maps exciting

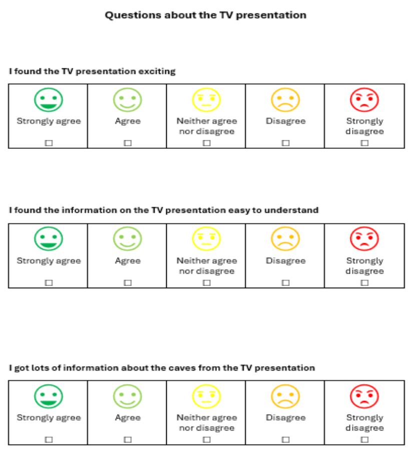
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐

I found the information on the printed maps easy to understand

Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐

I got lots of information about the caves from the printed maps

Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐



Questions about the TV presentation

I found the TV presentation exciting

Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐

I found the information on the TV presentation easy to understand

Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐

I got lots of information about the caves from the TV presentation

Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
☐	☐	☐	☐	☐

Appendix

Children’s Observation Sheet

Observation Sheet

Behaviour	DESCRIPTION	2D printed Maps	PARM	Presentation
AEngagement Level	Record the level of active engagement and interest. Note if the engagement is passive (just watching) or active (interacting, discussing).			
Comprehension	Note any verbalizations that indicate understanding or confusion. This includes questions asked to peer or teachers.			
Emotional Response	Observe and document any visible emotional reactions such as excitement, frustration, or boredom.			
Interaction Quality	Quality of interaction with the display: Are they manipulating it directly? Are they discussing it with others?			
Collaboration	Document instances of cooperative behaviour or discussions among the children regarding the display content			
Attention Span	Observe how long each child or group stays focused on the display without getting distracted.			
Preference Indication	At the end of the session, gather any verbal feedback or preferences expressed by the children regarding which display they found most engaging or informative.			

Appendix

Postgraduate Students Survey

Research Survey: Understanding Nottingham Caves Using PARM

Thank you for participating in this study. Your responses are crucial in assessing the effectiveness of the Projected Augmented Relief Model (PARM) in enhancing understanding of the Nottingham caves. Please answer the questions below to the best of your knowledge.

Pre-Interaction Questions

The following questions are intended to assess your initial knowledge about the Nottingham caves before using the PARM.

6. Have you ever visited the Nottingham caves?

- Yes
- No

7. What do you believe is the main reason for the clustering of caves in Nottingham?

- Natural geological formations
- Historical mining activities
- Random distribution
- I don't know

Post-Interaction Questions

Please answer these questions based on your experience after interacting with the PARM.

8. How effective was the PARM in enhancing your understanding of why caves are clustered in Nottingham?

- Extremely effective
- Very effective
- Somewhat effective
- Not very effective
- Not effective at all

9. After using the PARM, how would you describe your understanding of the geological features that influenced the location of Nottingham caves?

- Completely understand
- Mostly understand
- Somewhat understand
- Slightly understand
- Do not understand

10. Was the PARM helpful in visualizing the historical development of the Nottingham caves?

- Extremely helpful
- Very helpful
- Somewhat helpful
- Not very helpful
- Not helpful at all

11. How likely are you to recommend using a PARM to others for educational purposes?

- Very likely
- Somewhat likely
- Neutral
- Somewhat unlikely
- Very unlikely

12. What did you like most about the PARM demonstration?

13. What improvements would you suggest for the PARM demonstration?

General Feedback

14. Please provide any additional comments or feedback on your experience with the PARM:

Appendix

Pre-test for Postgraduate Students

University of Nottingham
UK | CHINA | MALAYSIA

Projection Augmented Relief Model (PARM) Evaluation Form

Course: **University:**

Undergraduate/postgraduate: **Gender:**

Date: **Time:**

Pre-Test Questions (Multiple Choice)

1. How many caves are there in Nottingham?
 A) Over 500
 B) About 800
 C) More than 1000
 D) Less than 400
2. What is sandstone primarily made of?
 A) Clay
 B) Sand
 C) Limestone
 D) Gravel
3. Which of the following is a common use for caves?
 A) Swimming pools
 B) Storage
 C) Shopping centres
 D) All of the above
4. Why are the Nottingham caves clustered in their specific locations?
 A) Due to random historical settlement patterns.
 B) Because of the unique sandstone geology conducive to cave formation.
 C) Due to modern urban planning.
 D) Because of the proximity to water sources.
5. Are Nottingham's caves natural or man-made?
 A) Natural
 B) Man-made
6. Why were caves made in Nottingham historically?
 A) For defence
 B) For mining
 C) As homes
 D) All of the above
7. What is a heritage asset?
 A) A type of currency
 B) A historically important place, object, or building
 C) A type of modern art
 D) None of the above
8. Why should you avoid building on gravel?
 A) It's too hard
 B) It's prone to flooding
 C) It's unstable
 D) It's expensive
9. What does "listed building" mean?
 A) A building up for sale
 B) A building scheduled for demolition
 C) A building of historical or architectural importance
 D) A newly constructed building
10. True or False: Caves often have rivers near them.
 A) True
 B) False

Appendix

Post-test for Postgraduate students

University of Nottingham
UK | CHINA | MALAYSIA

Projection Augmented Relief Model (PARM) Evaluation Form

Course: University: Undergraduate/postgraduate:

Gender: Date: Time:

Post-Test Questions (Multiple Choice)

1. How many caves are officially documented in Nottingham?
   A) 200
   B) 500
   C) 800
   D) 1000
2. Sandstone is primarily composed of:
   A) Silt
   B) Sand
   C) Pebbles
   D) Clay
3. Caves are commonly used for:
   A) Restaurants
   B) Residential homes
   C) Historical tours
   D) All of the above
4. Why are the Nottingham caves clustered in their specific locations?
   A) Due to random historical settlement patterns.
   B) Because of the unique sandstone geology conducive to cave formation.
   C) Due to modern urban planning.
   D) Because of the proximity to water sources.
5. The caves in Nottingham are primarily:
   A) Natural
   B) Man-made
6. Caves in Nottingham were historically used for:
   A) Religious ceremonies
   B) Refuge during wars
   C) Storage and dwellings
   D) All of the above
7. A heritage asset is:
   A) An ancient manuscript
   B) A place, object, or building of historical importance
   C) A valuable piece of jewellery
   D) A modern artwork
8. Building on gravel is not advisable because it is:
   A) Very cold
   B) Too dark
   C) Prone to shifting and settling
   D) Always underwater
9. A listed building is recognized for its:
   A) Low cost
   B) Architectural or historical importance
   C) Modern design
   D) High energy efficiency
10. True or False: Digging caves in gravel is generally unfeasible.
   A) True
   B) False