SENSES TOGETHER: Multimodal Literacy Learning in Primary Education

Final Project Report

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ARC Future Fellowship

ACU INSTITUTE FOR LEARNING SCIENCES & TEACHER EDUCATION

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The sensory orchestration project was conducted in collaboration with QAGOMA, Toledo Museum of Art, Big Picture Industries Inc., The Drama Merchant, and our participating schools.

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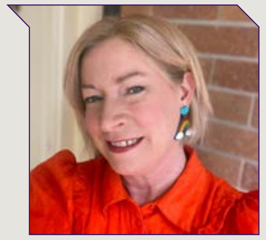
Kathy A. Mills is a Professor of Literacies and Digital Cultures at the Institute for Learning Science and Teacher Education (ILSTE), ACU, Brisbane and Australian Research Council (ARC) Future Fellow of this project. Her leading research examines gaps in current knowledge and educational uses of digital media and literacy practices, extending theories of multimodality, multiliteracies, New Literacy Studies, sensory studies, embodiment, and critical literacy. Professor Mills has published over 100 academic works, including award-winning books.



DR ELIZABETH HECK

Elizabeth Heck is an interdisciplinary researcher working across education, communications, and emerging technologies. She also has a background in community media arts and practice. Elizabeth has published in peer-reviewed journals and chapters in both Routledge and Springer books. She recently co-edited the collection Digital Disruption in Teaching and Testing. Dr Heck is a member of the Association of Internet Researchers (AoIR) and the Australian Teachers of Media (ATOM Queensland). Elizabeth is an Advance Queensland Digital Champion, where she has been involved in activities that contribute to creating more digitally inclusive communities.

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Alinta Brown is an interdisciplinary researcher with ILSTE. Alinta has degrees in communications and anthropology and works within the ARC project Sensory Orchestration for Multimodal Literacy Learning in Primary Education, as well as other nationally competitive education research grants. Alinta is an experienced mixed methods researcher analysing multiliteracy practices in schools, including use of virtual and augmented reality.

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Patricia Funnell is an experienced teacher and researcher with a background in sociology and journalism. With twenty years as a classroom teacher and over ten years as an active research assistant, Patricia brings a wealth of experience to education research projects.

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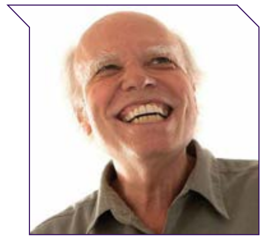
Lesley Friend was the Post-doctoral Fellow on the ARC Future Fellowship sensory orchestration project from April 2020 to July 2021.

International Advisors

Our team of highly respected and internationally renowned academic advisors has brought a wealth of experience in the areas of new literacies and discourse analysis, anthropology and sensory studies, linguistics, and semiotics. They provided the research team with invaluable conceptual input and feedback. They are:



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Project Partners

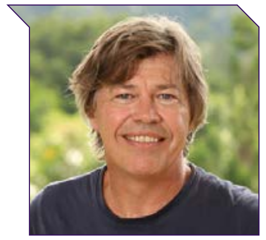
Our four project partners provided the research team with a wide range of valuable advice and practical assistance:

TOLEDO MUSEUM OF ART (USA)

The Toledo Museum of Art, a world-recognised for state-of-the-art multisensory programs for children and adults, provided the project with in-kind support, contributed to the development of relevant pedagogies, and hosted the summer program with Bowling Green University.

QUEENSLAND ART GALLERY/GALLERY OF MODERN ART (QAGOMA) (AUSTRALIA)

Queensland Gallery of Modern Art invited the research team to their artist-in-residence program to explore children's interaction with sensory displays and to investigate this dimension of their educational programs. The staff of GOMA were also instrumental in recruiting schools to participate in the project.



BIG PICTURE INDUSTRIES (AUSTRALIA)

Under the guidance of CEO Mark Williamson, Big Picture Industries collaborated with the team throughout the project, providing expertise and technology support for a variety of classroom activities. Big Picture Industries is a not-for-profit organisation that specialises in education programs in digital visual literacy and comprehension for schools and industry.

THE DRAMA MERCHANT (AUSTRALIA)

Nathan Schulz, aka The Drama Merchant, facilitated audio workshops in foley art during the project, and assisted in various classroom soundscapes activities.

Executive Summary

Literacy studies have traditionally focussed on the seen. The other senses are typically under-recognised in literacy studies and research, where the visual sense has been previously prioritised. However, spoken and written language, images, gestures, touch, movement, and sound are part of everyday literacy practices. Communication is no longer focussed on visual texts but is a multisensory experience.

Effective communication depends then on sensory orchestration, which unifies the body and its senses. Understanding sensory orchestration is crucial to literacy learning in the 21st century where the combination of multisensory practices is both digital and multimodal.

Unfortunately, while multimodal literacy has become an increasing focus in school curriculum, research has still largely remained focussed on the visual. The *Sensory Orchestration for Multimodal Literacy Learning in Primary Education project*, led by ARC Future Fellow Professor Kathy Mills, sought to address this research deficit.

In addressing this gap, the project built an evidence base for understanding how students become critical users of sensory techniques to communicate through digital, virtual, and augmented-reality texts. The project has contributed to the development of new multimodal literacy programs and a next-generation approach to multimodality through the utilisation of innovative sensorial education programs in various educational environments including primary schools, digital labs, and art museums.

Project Aims

The Sensory Orchestration Project was initiated to investigate and contribute to the advancement of new learning and pedagogical models of sensory orchestration for the enhanced multimodal and digital literacy learning of primary students. Broadly, it sought to address the problematic elevation of vision over other senses that limits students' perception and communication of different knowledge forms.

The project therefore had two aims:

- to understand the role of the senses and their orchestration in primary school multimodal literacy practices
- to develop a pedagogical model for educators to engage students in multisensory literacy learning experiences as they become creative producers and critical consumers of multimodal texts.

Project Overview

Developing multimodal and digital literacies in the primary years is a curriculum requirement, but more importantly, essential for engagement in life in the 21st century.

While students in all years of primary school in Australia are required to compose multimodal texts (ACARA, 2017), little work has been undertaken to understand how sensory orchestration—the senses working together—can effectively be understood and employed in the multimodal classroom. This project aligned with the national curriculum that encourages advanced pedagogical innovation in multimodal literacy, and which provides legitimate scope for teachers to take up new pedagogies. Student engagement with such technologies and pedagogies enriches learning and provides skills that support future workforce innovation and productivity.

Over three years, the Sensory Orchestration Project refined an understanding of students' sensory literacies using touchscreens and novel technologies, such as virtual and augmented reality, and developed innovative sensorial education programs through multi-institutional collaborations between schools, community hubs, and public galleries in Australia and the USA. The outcomes of the project have informed theory, practice, and policy for the education, arts, and community sectors.

This report provides a summary of the activities undertaken and findings of this research. It is categorised into key technology areas and concepts and project outcome summaries. The report also details implications for teachers, provides recommendations, and discusses the benefits of collaboration with industry for those involved in education policy and innovation.

Background

In order to better understand the multisensoriality of literacy and communication practices, including their technologies of mediation and production, the theoretical framework for sensory orchestration encompasses the concept of sensory literacies (Mills, 2016). Such a perspective is supported by a long-standing history of social scientific research that emphasises the sensory nature of human experience, perception, knowing, and practice, and draws on anthropology, sociology, and philosophy of the senses (Pink, 2009). While there has been a recognised sensorial direction in the anthropology of the senses (Howes, 2003), there is potential for theorising the sensoriality of literacy practice across a diversity of cultures (see Mills et al., 2013; Ranker & Mills, 2014).

This sensoriality is constantly changing in the context of an expanded array of hybrid digital technologies literacy practices that provide enhanced interactivity, improved mobility, and convergence with many platforms. Motion-sensing technology has made the perception of human movement and gestures essential to game play. Different sensory affordances are offered by full-body, three-dimensional, motion-capture technologies in gaming consoles. Players compete in game play using their gross motor skills, such as dancing, bending, jumping, kicking, twisting, swaying, and locomotion, all without touching the screen. In addition to the user's constant movement or the touching of the stylus on the screen, handheld video games are frequently designed to respond to the players' voice commands and/or purposeful breaths.

A growing body of research on approaches to the sensoriality of literacy practice acknowledges the importance of the body and embodiment in encoding and decoding (Mills et al., 2013; Nespor, 1997; Ranker & Mills, 2014). Yet there is currently no formal theoretical framework for literacy studies in this emerging area of study. The sensorial approach to literacy advanced here recognises that the body is crucial to an encounter when people communicate with one another, whether or not it involves digital tools. Therefore, understanding the process of meaning creation involves considering the important role of the body because "our bodies anchor us in the real, physical world in which we live and perform as social actors" (Scollon & Scollon, 2003). Thus, sensory approaches to literacy and digital practices focus on the embodied activity of human beings—a distinctive feature of sensory approaches to digital literacy practice.

Recent theories of sensory literacies and embodiment in multimodal communication, developed in response to a much more comprehensive worldly shift in writing and educational research, are at the heart of this study. These include demonstrating the significance of sensory-motor aspects of cognition and communication technologies, such as the use of haptics or touch to interact with the outside environment for learning (Minogue & Jones, 2006), embodied cognition (Corcoran, 2018), and embodiment and writing technologies (Haas & McGrath, 2018).

Project Technologies

This project explored literacy and communication practices using hybrid and emerging technologies to understand sensory orchestration. Researchers engaged in makerspaces and observed students' creative manipulation of digital imagery through photography. These technologies and concepts are defined and described further in the overview below.

MAKERSPACES

Makerspaces are community-based collaborative workspaces that provide people of all ages with access to tools, equipment, and resources for creating, inventing, and learning. They can incorporate the use of electronics equipment, 3D printers, laser cutters, and woodworking tools (www.makerspaces.com). Makerspaces also provide access to design programs, in addition to new and emerging multimedia technologies (Cooper, 2013; Gilbert, 2017; Marsh et al., 2019). These resources offer opportunities for individuals to turn their ideas into physical objects. These spaces are typically informal and are often established in "community facilities or education institutions where people immerse themselves in creative making and tinkering activities" (Adams Becker et al., 2016, p. 36).

Makerspaces offer a supportive environment for people of all skill levels to participate and are commonly located in community or educational spaces such as libraries, galleries, and museums (ADELE, 2023; Gilbert, 2017). One of the noted features of makerspaces is the emphasis on collaboration and knowledge sharing—encouraging people to work together to exchange ideas and to learn from one another (Hatch, 2014).

VIRTUAL REALITY

Virtual reality (VR) technologies use a head-mounted display (HMD) for a realistic visual experience and motion-tracking controls for haptic feedback, creating a computer-simulated environment in which users can immerse themselves (Velev & Zlateva, 2017; Jensen & Konradsen, 2018). Haptic feedback refers to the tactile or touch-based sensations that are provided to a user through a device or interface and is commonly used in VR systems and touchscreen devices. Haptic feedback enhances the user experience by providing realistic sensations or responses to user actions (Mills & Brown, 2022).

Research has demonstrated that virtual reality and other emerging technologies offer several benefits—they enhance memory, facilitate immediate learning, and increase student interest and motivation (Rasheed et al., 2015; Radianti et al., 2020; Metzinger, 2018). VR has also been found to aid in the comprehension of visual and spatial information and in improving decision-making skills in simulated scenarios (Jensen & Konradsen, 2018; Rasheed et al., 2015). In addition to education, VR has expanded its applications to include storytelling, socialising, and playful learning experiences.

Virtual reality technology offers opportunities for accessing learning scenarios that are challenging to replicate in traditional classrooms. For instance, it allows real-time observation of simulations of various phenomena (Huang et al., 2010) while providing experiential and interactive learning environments that promote dialogue and abstract thinking (Fernandez, 2017).

AUGMENTED REALITY

Augmented reality (AR) enhances the real-world environment by adding virtual elements to it, and is experienced via devices such as smartphones, tablets, or smart glasses (Blevins, 2018; Pellas et al. 2019). AR works by using sensors or the camera of the device to capture the real-world surroundings, and then overlays the virtual content onto that view. This contrasts with virtual reality, which creates a fully immersive computer-generated environment. The virtual content in AR is typically interactive and responds to the user's actions and the environment (Akçayır & Akçayır, 2017; Wu et al., 2013).

MIXED REALITY

Mixed reality (MR) is a technology that blends elements of both virtual reality (VR) and augmented reality (AR) to create a hybrid experience that combines real and virtual worlds. In mixed reality, virtual objects and digital content are not only overlaid onto the real world but also interact with and respond to it in real-time (Maas & Hughes, 2020; Rasimah et al., 2011).

Unlike augmented reality, where virtual content is simply overlaid onto the real world, mixed reality enables users to interact, manipulate and observe virtual objects from different angles (Maas & Hughes, 2020). Mixed reality environments typically use specialised headsets, such as Microsoft's HoloLens 2™, which allow users to see and interact with virtual objects that appear as if they exist in the physical space around them.

DIGITAL IMAGERY

Digital imagery—including photography—is the creation and manipulation of visual content using digital tools and technologies. It involves the capture, editing, storage, and sharing of images in digital formats. Digital imagery offers many learning opportunities (Chai, 2019) that promote communication skills, aligning with the Australian Curriculum's general capabilities (ACARA, 2023a). These include digital literacy, critical and creative thinking, and literacy, as students learn to critically analyse and interpret images, create their own visuals, and effectively communicate their ideas (ACARA, 2023a; Kedra, 2018; Stokes, 2002).

Research Design

Our research design was an international qualitative multi-site intervention involving industry collaboration with art galleries and the schooling sector. The study involved the research participation of primary and junior secondary students as well as their teachers, representing both public and private schools located in southeast Queensland, Australia. We collaborated with the Toledo Museum of Art in the United States and partnered with QAGOMA, Big Picture Industries, and The Drama Merchant in Australia to further expand our research efforts to engage with school-aged learners in out-of-school settings.

The data collected and analysed for this study were multimodal. Think-aloud interviews were conducted with students and semi-structured interviews with teachers and students were utilised as part of our data collection methodology, as outlined by Friend and Mills (2021), Mills and Brown (2022, 2023), and Mills, Scholes, and Brown (2022).

We gathered and analysed digital artefacts—including video and photographic imagery—from our participating students to support our analysis. Video captured students' embodied movements as they engaged in literacy practices while using makerspaces and technologies. When applicable, Open Broadcaster Software (www.obsproject.com) was utilised to record students' virtual reality or hybrid vision as they used the head mounted display. iPad recordings captured student use of augmented reality. Audio-visual recordings were made of students creating soundscapes. Students' hand-drawn illustrations and written artefacts also formed part of the overall dataset.

For more comprehensive information regarding the project's methodology and design, please refer to the Project Publications section of this report.

Project Outcomes

This section of the report comprises key project outcomes from each type of technology in which we explored the senses and multimodality—Makerspaces, Virtual Reality (including multiliteracies pedagogy), Mixed Reality, Augmented Reality, and Digital Imagery.

Outcomes from Makerspaces

Makerspaces are innovative educational spaces that bring together various forms of media and communication to enhance learning. They offer opportunities for both physical and digital engagement and promote different ways of knowing (New London Group, 2000). These spaces emphasise collaborative and networked learning and utilise emerging technologies that are becoming increasingly vital in contemporary society. Makerspaces provide unique learning environments that incorporate sensory literacies and embodied practices, allowing learners to express their ideas and knowledge through multiple ways (Adams-Becker et al., 2016; Cooper, 2013; Friend & Mills, 2021; Gilbert, 2017; Hatch, 2014). See Figure 1, for an example of one of the makerspaces from our research.

The objective of this component of the larger study was to investigate the significance of touch, sound, smell, and their orchestration in the creative process of producing media within educational and community makerspaces. Touch emerged as highly significant in the students' interaction with mixed-media texts in makerspaces. Although touch has only been recently explored in the realm of digital media production, it plays an important role in perceiving the world, especially in the context of two- and three-dimensional creation, allowing individuals to explore texture, temperature, and vibration. By engaging the hands, fingers, and other parts of the body, touch provides both agency and knowledge (Friend & Mills, 2021).

Qualitative research was undertaken collaboratively with U.S. and Australian industry and research personnel in three makerspaces/research sites in which students created their designs. The aims were to consider how students, in creating their designs, used touch and how touch was orchestrated with other multisensory resources. The primary and middle school-aged students participated in activities at The Toledo Museum of Art, in the United States and QAGOMA, in Australia. The programs had been intentionally developed for participating students to create a range of mixed-media designs including digitally enhanced clay sculptures that incorporated programming with electronic Arduino™ kits (or e-sculptures). Participants could also work with three-dimensional pens and paints (examples of these materials can be seen in Figure 1).

Based on their observations, Friend and Mills (2021) created a unique typology with how students in makerspaces utilised touch to create a variety of artefacts.

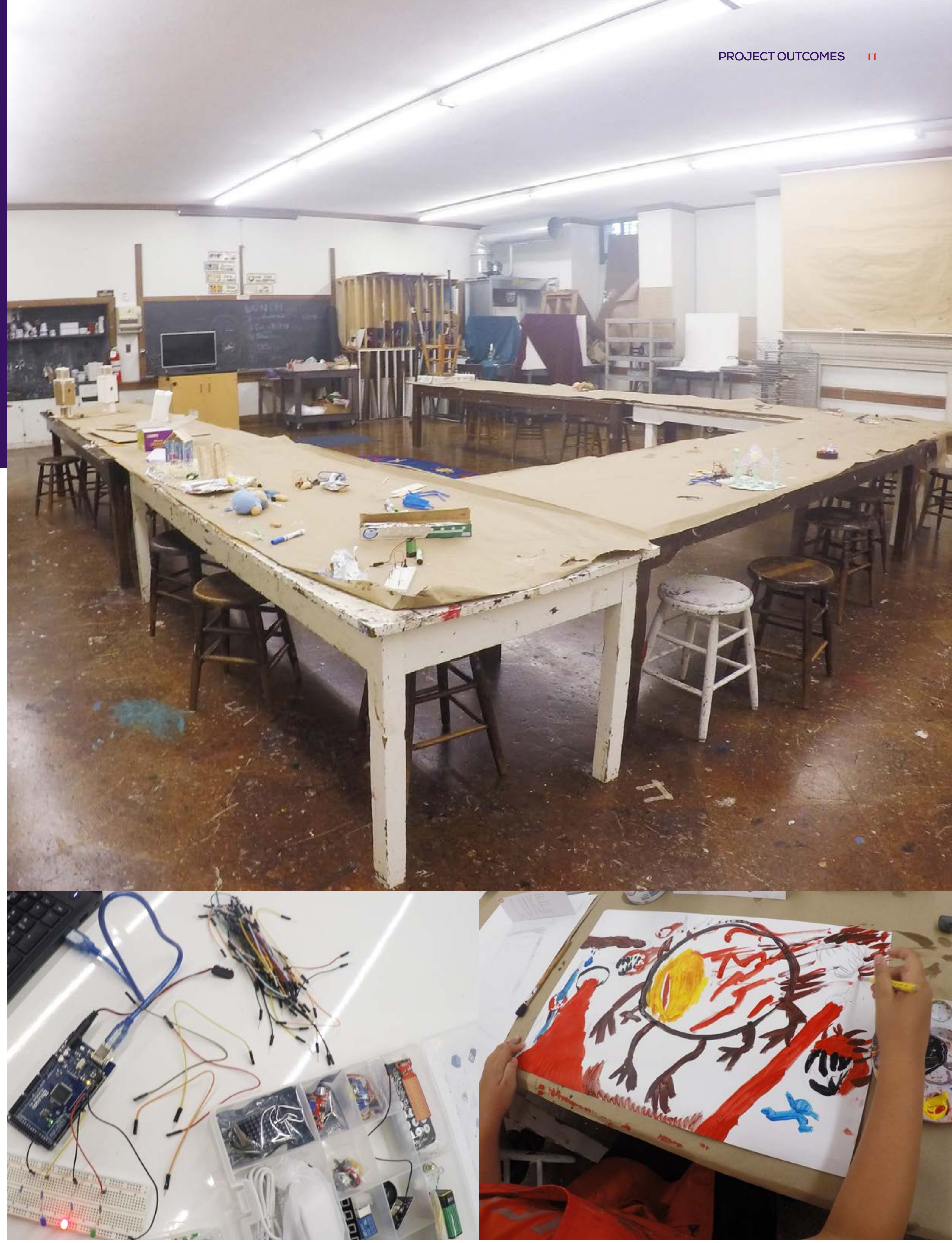


Figure 1. An example of the various makerspace activities at the Toledo Museum of Art.

TOUCH TYPOLOGY IN MAKERSPACES

As Friend and Mills (2021) noted, touch had recently attracted research interest as a preferred method of navigating contemporary digital technology, exploring keyboards, gaming controllers, and touch displays (Neumann & Neumann, 2014; Walsh & Simpson, 2014). Touch has been found to play a vital role alongside creativity, making this an important area to explore.

As a component of the art and technology camp in the U.S., students designed and made e-sculptures from recycled materials and used computers that incorporated programmed flashing lights and Arduino™kits. An Arduino™ kit is an educational electronics package that provides the tools to teach students the basics of electronics concepts before progressing to building more complex circuits.

Our research found that touch was used to connect the mind and objects in creative settings. Such a system is congruent with embodied cognition research, which has shown that experiences of hand movements and touch, as well as interactions with physical tools and technologies for design, "profoundly modify... embodied experience and practices" (Haas & McGrath 2018, p. 127; See Friend & Mills, 2021).

As a result, Friend and Mills (2021) developed the typology which included four specific categories of touch—explorative, creative, auxiliary and evocative—which are outlined next.

Explorative touch

Students demonstrated explorative touch, where they actively perceived, explored, and felt items. In both the U.S. and Australian galleries, students discussed deliberately feeling for and incorporating specific textures, such as "soft", "waxy, "smooth," and "rough," into their work. Students also explored this with clay models, and sculptures, including that of model cars (as seen in Figure 2). Such explorative touch was intrinsic for students in the creation of their physical objects (Friend & Mills, 2021).

Creative touch

The students' think-aloud interviews frequently referred to creative touch that is motivated by imagination and creativity. In terms of their decision making, students' thinking, their physical behaviour, and their understanding of touch were crucial and connected (Wilson, 2002). This was noted in examples of the creation of technology-based sculptures and drawn artwork (Friend & Mills, 2021).

Auxiliary touch

Auxiliary touch combines materials with sensory experiences and is frequently essential in production and design and the employment of tools as "body-auxiliaries" (Allen-Collinson & Hockey, 2011; Friend & Mills, 2021; Mills, Unsworth, & Exley, 2018). Body-auxiliaries refers to the engagement of other tools with sensory experiences. In this instance, students created their designs by engaging various tools, including pencils, paint brushes, and keyboards.

Evocative touch

Many young participants described how touching their design brought up many memories and emotions. The creation of e-sculptures, kinetic digital art, and video demonstrated the use of evocative touch—touch that evokes emotions or memories. Examples of these student creations can be seen in Figure 1 and Figure 2 above. This is significant as the research on embodied cognition has shown that bodily activity—rather than disembodied or abstract symbols—serves as the foundation for a large portion of human memory and emotions (Gibbs, 2005). Evocative thoughts in relation to touch were observed across all research sites (Friend & Mills, 2021).

The significance of various types of touch

This typology identified the various types of touch—explorative, creative, auxiliary, evocative, and orchestrated and transformative—observed in students' media practices when engaging in creative literacy practices. These findings are pertinent to the educational and societal contexts of creative digital media production (Friend & Mills, 2021). Furthermore, this research demonstrates the connection between touch and the mind and materials within creative spaces. This aligns with the findings of research on embodied cognition, which emphasises how the physical experiences of hand movements, touch, and interactions with tangible tools and design technologies can significantly transform embodied experiences and practices (Haas & McGrath 2018).

By expanding on previous notions of embodied cognition and haptics within educational makerspaces (Gibbs, 2005; Haas & McGrath, 2018), this research has effectively showcased the specific ways in which haptic experiences and other kinaesthetic activities are intricately intertwined with human learning, creativity, memory, and knowledge representation (Friend & Mills, 2021).

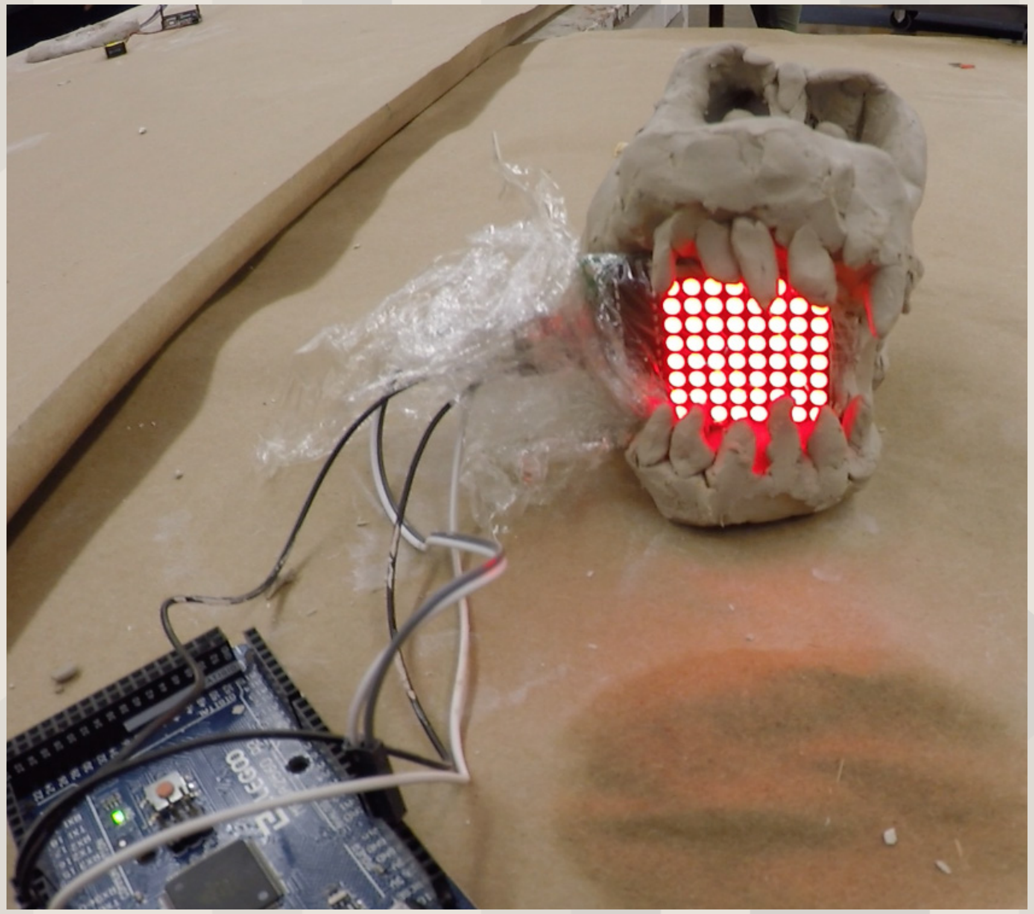


Figure 2. Students utilising touch in their makerspace activities at the Toledo Museum of Art, including in light-up sculptures and clay creations.

ACOUSTICS AND SOUNDSCAPES

In addition to the significance of touch, the sense of sound was also explored in the makerspaces with various acoustic and soundscape activities. An example was students' engagement with the sense of sound was exemplified in a student-authored video on 'slime' creation. The video not only brought attention to significant acoustic effects resulting from the manipulation of popping, crunching, and suction sounds, but also showcased how touch functioned as part of a sensory experience that integrated auditory and visual elements (Friend & Mills, 2021). An example of these slime touch and acoustics can be seen in Figure 3.

We also explored the concept of soundscapes. The term soundscape was first defined by Southworth (1969) as "the quality and type of sounds and their arrangements in space and time" (in Grinfeder et al., 2022, p. 1). Furthermore, in relation to soundscapes in literacy studies, and as noted by Mills, Unsworth, and Scholes (2023, p. 91), "(t)he digital production and distribution of sonic media is a rapidly changing landscape… Humans and civilisations encounter transformed soundscapes – sonic or acoustic environments – layers of meanings in our daily lives that are a vital part of our multisensorial emplacement in the world (Schafer, 1993)". In our research context, we observed the creation of acoustic or sound effects to craft an immersive audio scene using various types of materials.

In collaboration with The Drama Merchant, Nathan Schulz, an Australian-based audio theatre educator and performer, creation of these soundscapes involved using a foley –appropriate sound effects, space, and materials – through which students created the sounds of a steam train, and of a boat in a storm (see Figure 4). Examples of these soundscapes can be found at this Soundcloud link: https://soundcloud.com/kathy-mills-128619814

The significance of creating soundscapes

The digital production and distribution of sonic media is rapidly changing, with some referring to an 'audiovisual turn' in fields from applied linguistics to media studies, and from musicology to philosophy (Mills, Unsworth, & Scholes, 2023). Explorations of sound within multimodal literacy practices in the digital age are important because sonic elements often carry a significant textual meaning that is felt viscerally in the body (Cope & Kalantzis, 2020). Transformed soundscapes—sonic or acoustic environments—offer layers of meanings that are a vital part of our multisensorial emplacement in the world (Schafer, 1993). Elements of sounds, music, speech, or silence, form an often-invisible backdrop that can be read as an "auditory epistemology of everyday life" (Bull, 2000 in Mills, Unsworth, & Scholes, 2023, p. 91).

Creating soundscapes allowed students to explore and optimise a range of sensory literacy practices. Students create non-verbal messages, transcending language barriers. They generate narratives using their bodies and the manipulation of physical objects, captured as digital audio files. We found that such multimodal text composition offered students the freedom to explore imaginative landscapes, synthesizing sounds to create scenes beyond their own experiences, building sonic worlds that were complex and realistic.

Figure 3. An example of students working with 'slime balloons' that provided both a tactile and acoustic sensory experience.

Figure 4. A demonstration of the foley and sound effects materials that students would use to create their soundscapes.

Outcomes with Virtual Reality Technology

Virtual reality (VR) technology is increasingly being used in education, but there is limited research on its effectiveness for students' multimodal communication in writing and literacy studies. The importance of exploring new methods of embodied meaning-making in VR environments is yet to be thoroughly examined. This research gap was explored in our study, and there remains significant potential for expanding the use of sensory experiences in multimodal language and literacy learning.

HOW DO VR TECHNOLOGIES SUPPORT LEARNING?

VR technologies can offer experiential and interactive learning settings that encourage dialogue and abstract thought (Fernandez, 2017). According to Hussein and Nätterdal (2015), classroom use of VR technology for learning is expected to develop exponentially across all educational levels, from early childhood through to higher education. Recent use of virtual technologies has expanded to include storytelling, socialising, and learning through play (Huang et al., 2010, Steed et al., 2018).

For this phase of our research, data collection and analysis included multimodal and digital data and focused on the learning experiences of upper primary students. Participants engaged in multimodal composition, in:

1. Story writing, by retelling Greek myths with accompanying illustrations and virtual painting using the Google TiltBrush™ (Mills & Brown, 2022), and

2. Virtual painting, using head mounted display (HMD) and motion sensors. We examined the potentials for new forms of embodied multimodal representation in VR including whole body, haptic, and locomotive movement (Mills, Scholes, & Brown, 2022).

As a result, the research team studied two processes in immersive VR environments with student digital media making: transmediation and embodiment.

TRANSMEDIATION, EDUCATION POTENTIALS, AND LEARNING WITH VR

When a student transfers knowledge from one expression plane, symbolic system, or communicative mode to another, such as using dialogue to explain concepts from a book or a paragraph to explain a diagram, transmediation is taking place (Mills & Brown, 2022; McCormick, 2011). Suhor (1984) first proposed the concept of transmediation and emphasised the distinct organising principles of each representational mode or sign-making system (e.g., drawings or written words). The educational potential of VR technologies is supported through knowledge of transmediation. This can include across written, hand drawn, and virtual formats. However, the concept of transmediation in virtual reality learning had not yet been explored (Mills & Brown, 2022).

The purpose of this phase of the study was to explore the opportunities and limitations of virtual reality for translating ideas from conventional modes of writing and drawing to the immersive mode of virtual painting. In this component of our research, Mills and Brown (2022) identified the following main themes:

IMMERSION AND THREE-DIMENSIONALITY

Many of the students found that virtual painting, with its immersive and three-dimensional experience, helped them express ideas in different ways. VR allows the student to feel immersed by the experience—being completely surrounded by a virtual world that feels real, blocking out the physical world (Jensen & Konradsen, 2018). VR provided unexpected ways in which the students could imagine their stories and ideas. Students quickly learned that instead of depicting a scene two-dimensionally, they could construct a three-dimensional landscape, and be personally situated within it. For example, some students created the city wall of Troy and were then able to stand in the virtual shadow of that wall. The ability to have more than one setting was a stimulating feature that made the students' stories come alive. Students discovered they could depict both the exterior and the interior of a three-dimensional scene. For example, the textural outer of the Trojan horse could be depicted as a 'complete' image, then by moving within that image, the objects placed inside the belly of the horse could also be shown yet had not been visible from the outside (See Figure 5). The majority of the students felt it was helpful for their creativity (Mills & Brown, 2022).

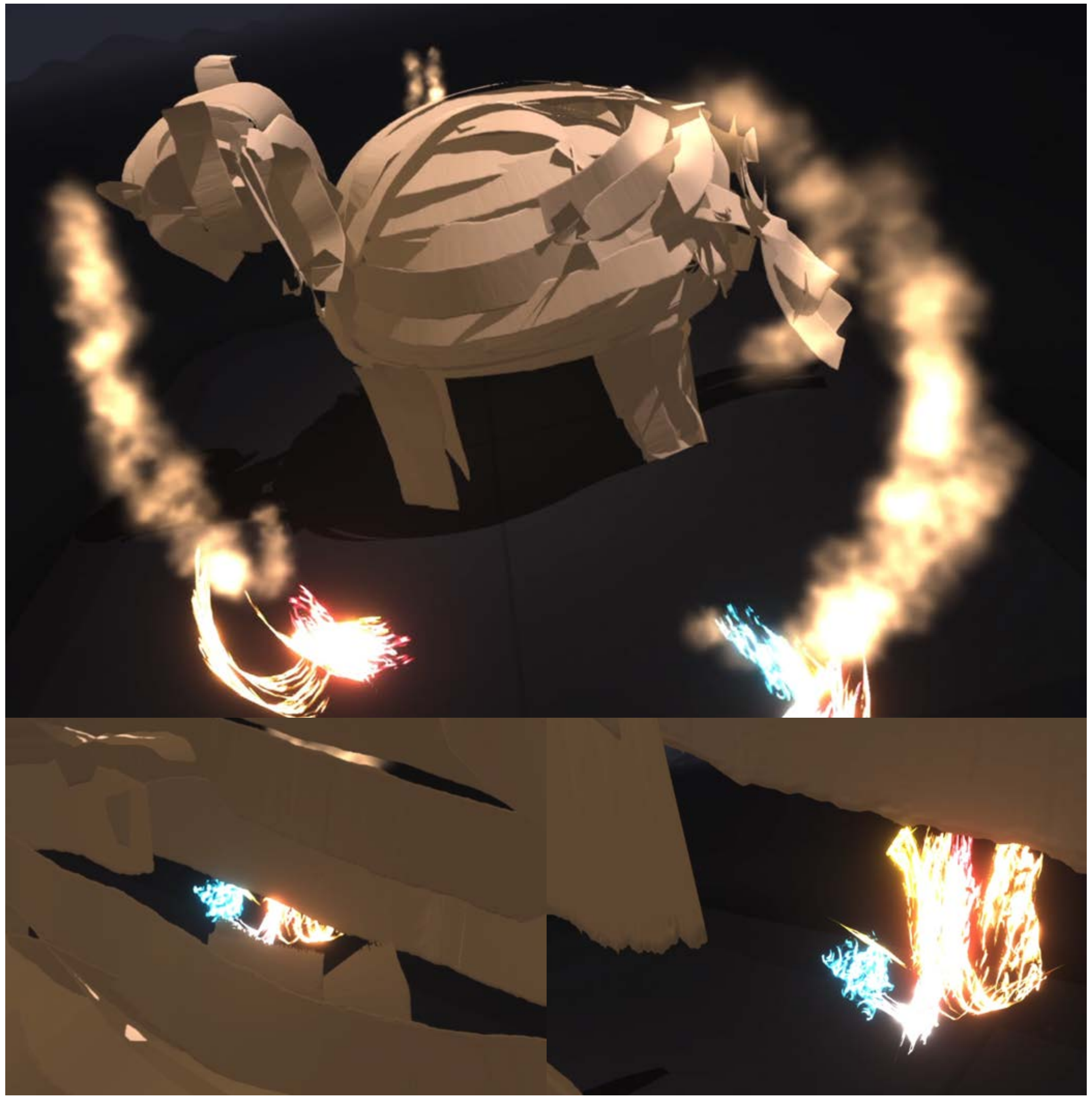


Figure 5. A student example of a VR created 'Trojan horse', where smoke and fires can be viewed both inside and outside of the virtual image, creating an immersive and three-dimensional experience.

PRESENCE AND SUBJECTIVE PERSPECTIVE

When students shifted their ideas to the virtual painting mode, the majority experienced a sense of presence (Mills & Brown, 2022). While the quality of the immersion and multisensory feedback influence the scope of the experience (Light, 2019), presence refers to the subjective sensation of being there in a virtual setting, as opposed to looking on as an outsider (Kavanagh et al., 2017). In VR settings, presence is a subjective state of the user and not a function of the technology (Slater et al., 2009). Feeling like they were really there, students felt connected to their constructed virtual environments and could actively take part. In the Greek narratives students were able to position themselves inside the stories. This was observed when students created the wings of Icarus around their own bodies and the sea beneath their own feet, or when they moved through their virtual landscape as a story character. In another example, students experienced subjective social presence while spray painting in a virtual subway. As each student entered the virtual environment separately, they responded to the sense of being there with other students' artwork. Students' felt like they each contributed to the collective social act of creating street art. In the process of transmediating their stories or spray-painting street art, the virtual environment provided by the HMD supported students to feel present, without visual distractions from the real world (see Figure 6).

SENSORY ILLUSION

As Mills and Brown (2022) noted, "[t]he role of sensory illusion in transmediating meanings from conventional to virtual modes was observed to both enable and constrain the learners at times, with more frequent occurrences of constraints" (p. 191). In VR environments, sensory illusion can appear in a variety of ways, each of which adds to the overall impression that virtual actions, locations, and bodies are real. According to Steed et al., (2018), different types of sensory illusion in virtual experiences can enhance the user's overall subjective sensation of presence.

Our students often had mixed responses to sensory illusion, and it was not always perfect. As such, some students found the virtual and physical spaces confused at times, having difficulty confidently moving around in the virtual world (Mills & Brown, 2022). Working with a sense of scale three-dimensionally, often presented a challenge for students. However, it did allow students to participate in the creation of their virtually painted artworks from various angles and vantage points.

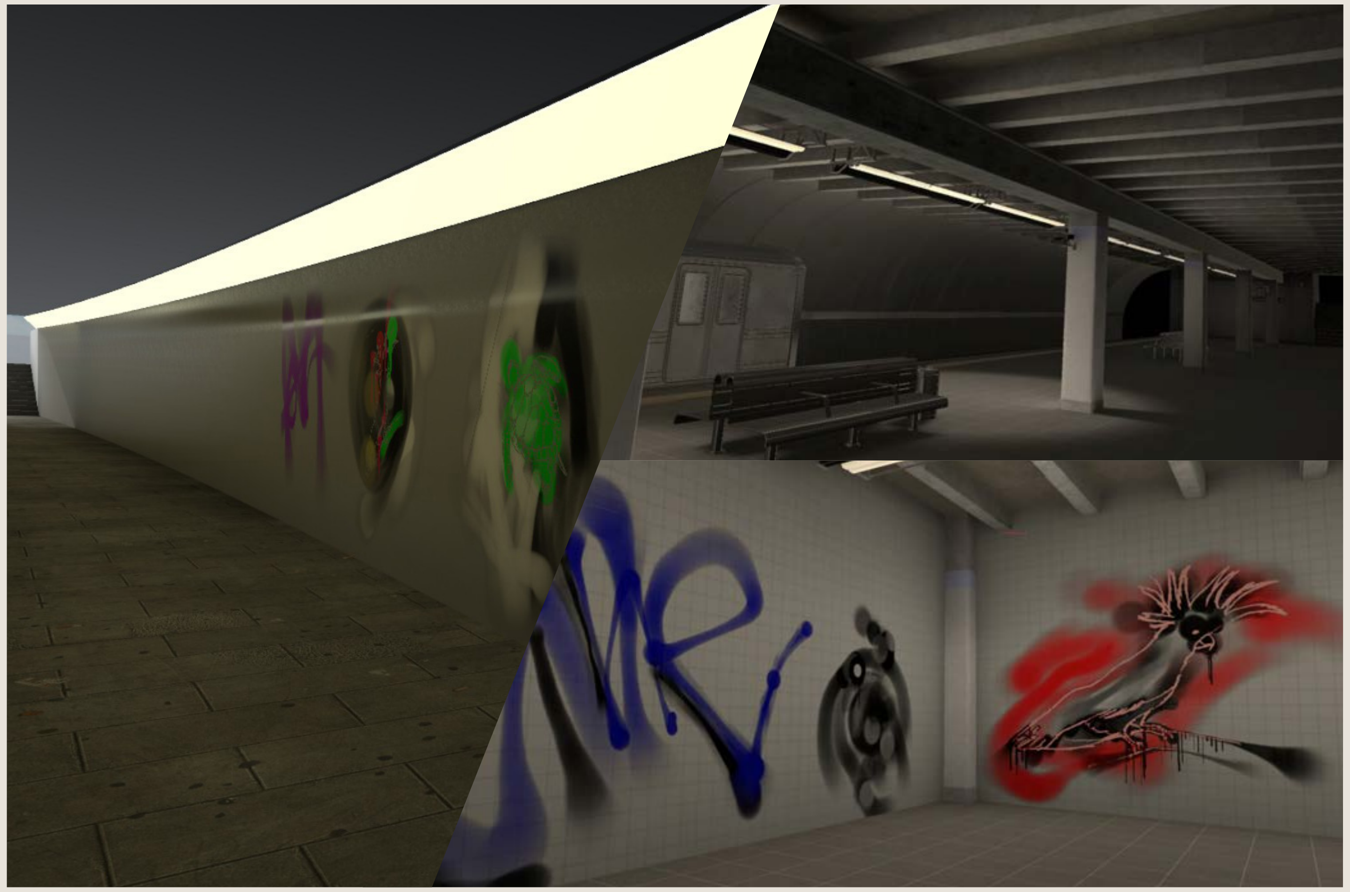


Figure 6. An example of VR spray painting subway art.

INTERACTIVITY USING MOTION TRACKING

Motion tracking interaction was shown to be both enabling and restricting for content transmediation in the virtual painting mode (Mills & Brown, 2022). Digitising user movement is a crucial element that supports movement-based interactivity by responding to the user's sensory input. Users may move around in a virtual space, interact with virtual objects, and use controllers to create virtual designs thanks to motion tracking, which detects head movement and gestures, and updates the user's view in the virtual world accordingly (Velev & Zlateva, 2017). At times, students felt supported by the virtual painting on the screen that would correspond to their haptic movement and head and body position, allowing for crouching, turning, and stepping. Students were able to use much larger movements than those involved in drawing or writing to create their stories. However, limitations in adapting their written stories to the virtual scenario were evident where students attempted to precisely replicate two-dimensional drawings with fine details, or when trying to include all aspects described in a written story.

VIRTUAL REALITY AND ITS IMPACT OF LEARNING AND PEDAGOGY

In summary, virtual reality (VR) is interactive and responds to the user's movements in a fully immersive environment. This allows for opportunities and limitations when it comes to translating ideas from writing and drawing into the virtual mode. The immersive and physically interactive nature of VR presents a new element, but there are challenges in representing fine details since there are no tangible surfaces or artificial stimuli to create a sense of pressing against a physical surface (Mills & Brown, 2022). An example of how meaning was transmediated across modes can be seen in Figure 7.

As noted, results of this study have demonstrated that VR technologies can be employed to promote the translation of information from conventional to immersive modes. Even though a task appears to need a straightforward replication of information acquired by reading, hearing, drawing, and writing, translating this knowledge into a virtual modality is a generative process, rather than a straightforward replication of content. Learners must reconfigure their knowledge, using increasingly complex, multimodal, immersive, and interactive, three-dimensional—yet physically intangible—learning environments (Mills & Brown, 2022).

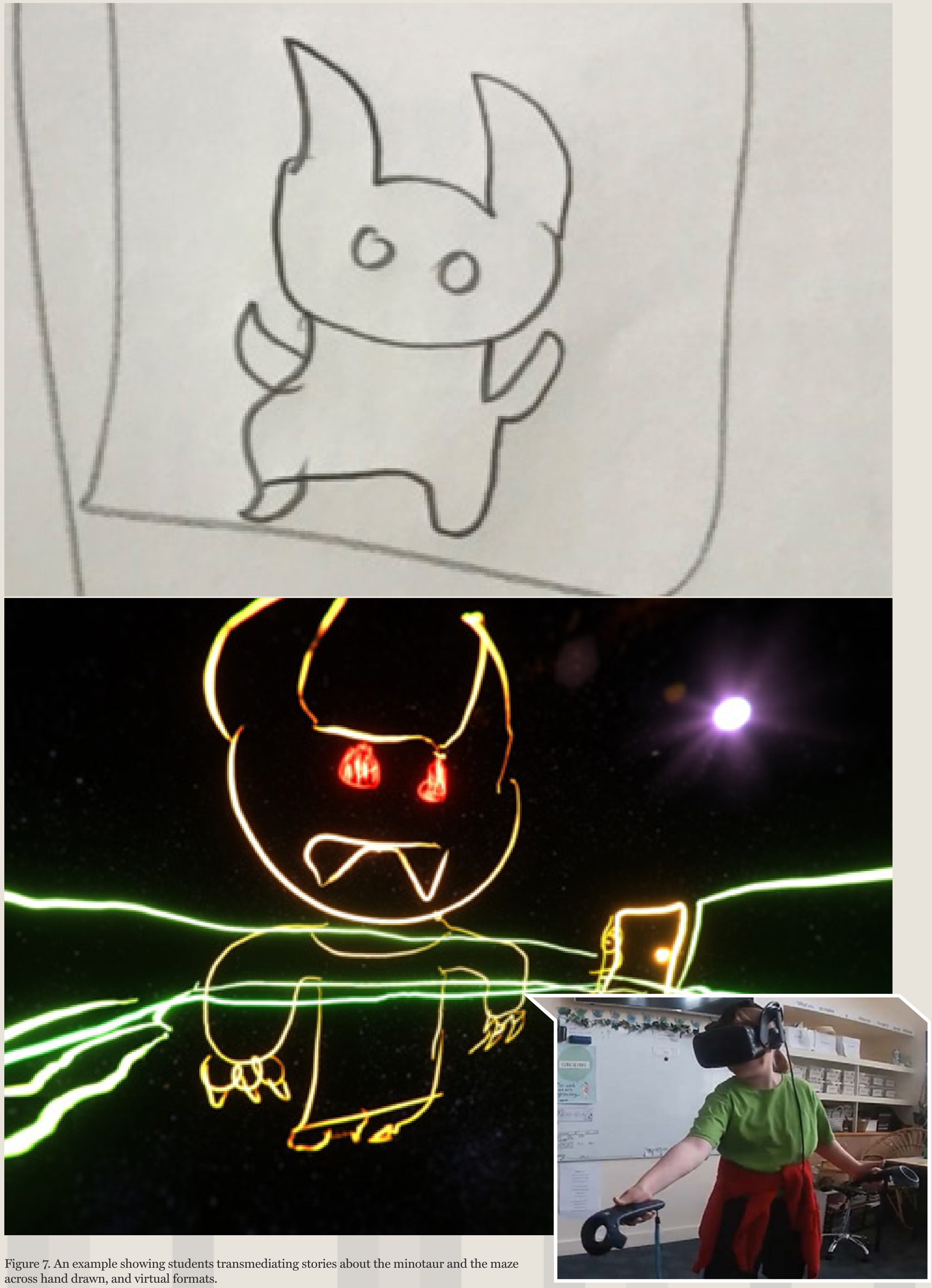


Figure 7. An example showing students transmediating stories about the minotaur and the maze across hand drawn, and virtual formats.

EMBODIMENT IN VIRTUAL REALITY

Human cognition and creativity are inseparable from bodily experience and sensorimotor processes (Corcoran, 2018). Utilising VR technologies for learning presents an opportunity for embodied meaning-making and increased engagement through the inclusion of the user's vision, haptics, locomotion, and hearing, rather than merely privileging vision alone (Jang et al., 2017 in Mills, Scholes, & Brown, 2022).

Communicating with the modal affordances of VR painting uses an expanded sensorium. In other words, it allows the "whole sensory apparatus of the body... to operate in consort to make up perceptual systems" (Duncum, 2012, p. 183); the expanded sensorium afforded by VR meant students utilised a wider range of movements than those performed in conventional writing and drawing to make meaning. This embodiment was explored by Mills, Scholes, and Brown (2022), utilising virtual painting with the Google TiltBrush™, to study how students produced three dimensional paintings that expressed mood.

WHOLE BODY MOVEMENT, HAPTICS, AND LOCOMOTION

The main mode of exploring whole body movement was virtual painting, a hybrid way of communicating where participants paint with virtual brushes utilising a digital gaming controller that produces visible, intangible ink into the air (see Figure 8). Virtual painting does not require surfaces to paint on or the mixing of paint, in contrast to traditional painting or sketching.

Virtual painting does not abide by physical rules like gravity. As a result, utilising in-air haptics, artists produce three-dimensional, gravity-defying images that appear suspended in the immersive environment.

Virtual painting does not abide by physical rules like gravity. As a result, utilising in-air haptics, artists produce three-dimensional, gravity-defying images that appear suspended in the immersive environment.

Virtual painting includes a variety of body movements (Friend & Mills, 2021; Mills, Scholes, & Brown, 2022), as outlined in Table 1.

BODY MOVEMENT	DESCRIPTION
Hand movements/haptics	• Repetitive up and down; co-ordinate left and right (selecting controls); arcs, sweeping; fine/gross motor; side to side; close, far away from body. • Arms stabbing; slow careful, quick sweeping; horizontal dragging; straight arms to reach high; strokes to paint colour. • Wrist turning; dabbing; slashing; making circles; spirals; painting near and far.
Locomotion: Foot-legs	• Wide apart/close together; knees bent/straight legs; stepping over objects; striding; stepping forward and back; turning around in a circle; side stepping; about facing. • Lowered to the ground, legs bent underneath supporting weight; kneeling; feet placed with toes on floor for quick uprising; crouching with one knee down; moments of no movement as attention directed to controls. • Crossovers; load switching; squats on tip toes; pivots; shuffle; parallel; toes pointing out; toes pointing toward each other; feet in contact with one another.
Head, torso	• Nods, leans head side to side, looks up/down, looks left/right, aligned/not aligned with body, follows active painting hand. • Gazes (stationary), looks at painting, ground, hand controls, around the three-dimensional space, looks around/under three dimensional objects/lines. • Torso twists right/left, bends/crouches/arches backwards, follows rest of the body, accommodates arm/leg movement, orientation towards painting, forward movement of shoulders.

Table 1. Some examples of body movement in the context of VR (adapted from Friend & Mills, 2021; Mills, Scholes, & Brown, 2022, with permission).

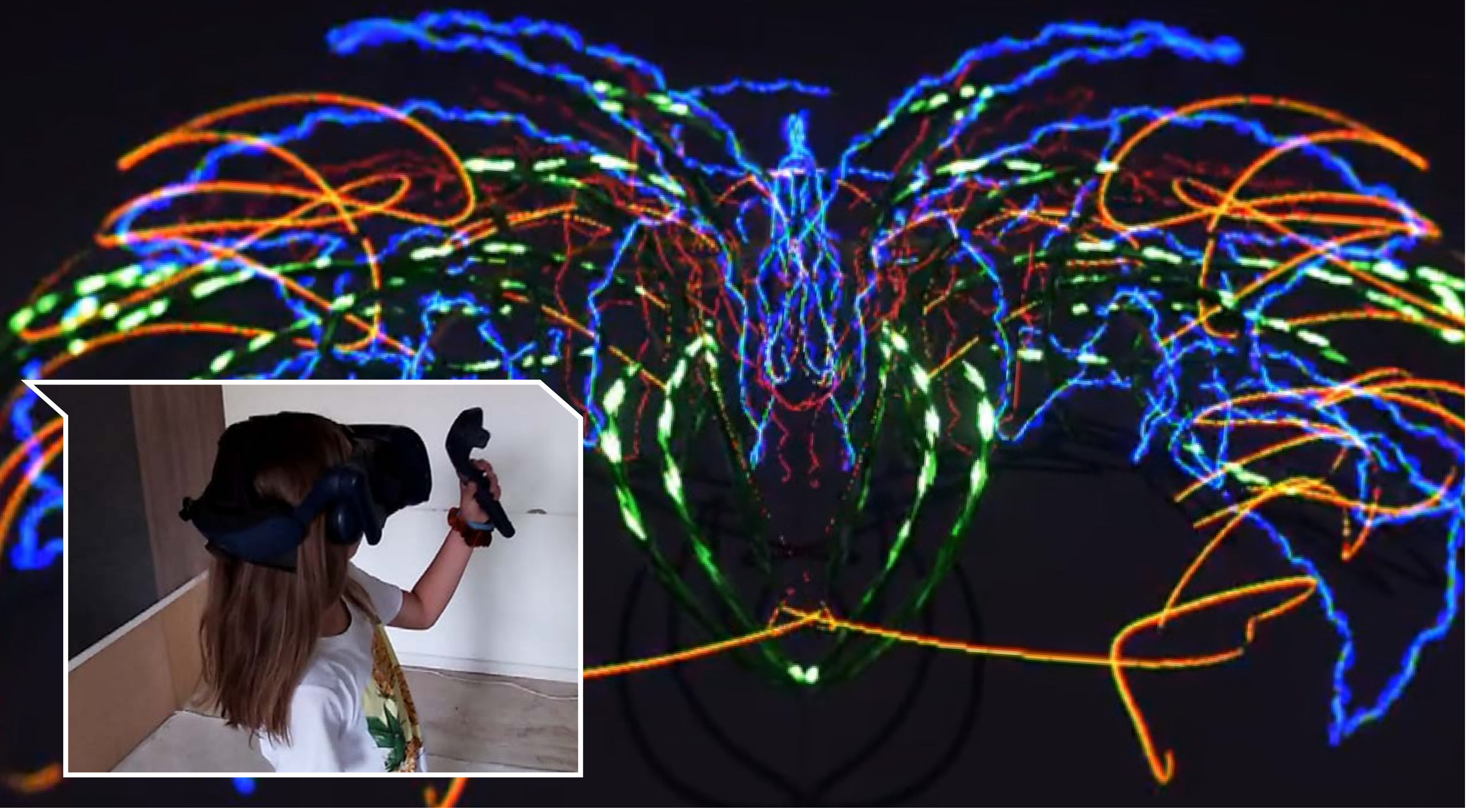


Figure 8. Examples of virtual painting using VR technology.

As seen in Table 1, student participants used their whole body as they immersed themselves in the activity. Movements included nodding their head, torso twists, squats, pivots and stepping over objects. From our observations, virtual reality (VR) technologies have become more accessible for expressing creative ideas, and there are new opportunities for using our bodies and senses to communicate in different ways. Here, we have been able to demonstrate that student participants used their senses and engaged body movements in creative actions in three-dimensional and immersive environments.

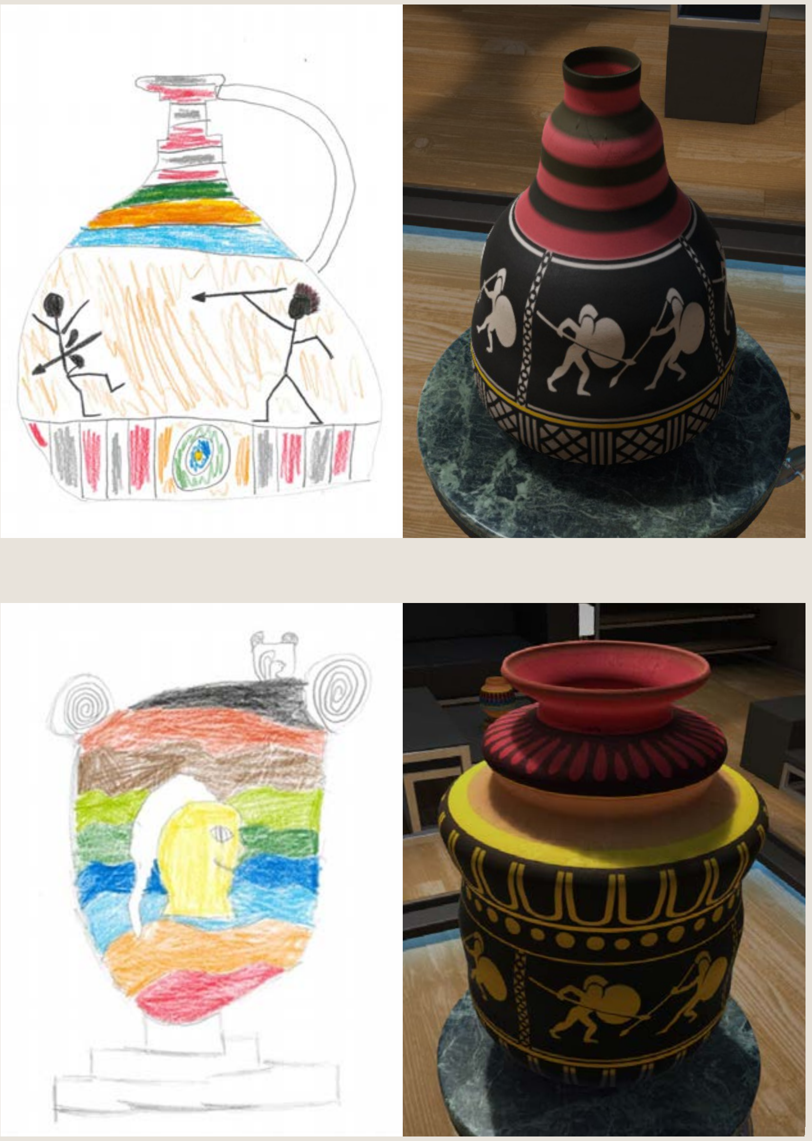
MULTILITERACIES PEDAGOGY AND 3D MULTIMODAL DESIGN

In addition to the exploration into transmediation and embodiment in VR, the research team investigated virtual Roman pottery creation in the context of multiliteracies pedagogy (Mills, Brown, & Funnell, under review). In this part of the VR research, we built upon the concepts of multiliteracies of the New London Group (2000). We aimed to understand the process by which primary school students created three-dimensional VR artefacts, from the initial gaining of knowledge to applying it in the VR context. Textual practices involved using different modes of meaning and drawing on culturally and historically available semiotic or sign-making, resources. In this component of the research, we provided upper primary students (aged 10-12 years) with the opportunity to create virtual reality Roman vessels, as shown in Figure 9.

We approached this as a form of multimodal text design, where users transformed combinations of visual and technical design elements and made choices—such as 3D clay shapes, hieroglyphic patterns, and colours—to create redesigned versions (Mills, Brown & Funnell, under review). The production of artefacts, whether using real clay or virtual materials, is always influenced by social, cultural, and embedded knowledge within the production technologies (Kohring, 2012). Our students' process of designing earthenware vessels involved planning, intention, artistic creativity, playful experimentation, and spontaneous intuitive decision-making that evolved through moment-to-moment choices (Moo-Young et al., 2021). Figure 10 provides examples of the students' work, including their corresponding drawn design and annotations.

The VR technology allowed students to embrace the immersive novelty of their virtual vessel creations. It afforded them the opportunity to explore sophisticated techniques beyond those possible in the "real world". For example, students could paint both 'inside' and 'outside' their artefact with consistency and uniformity, as seen in Figure 11.

Figure 9. A student example of colour patterning on their Roman pottery vase using VR technologies.

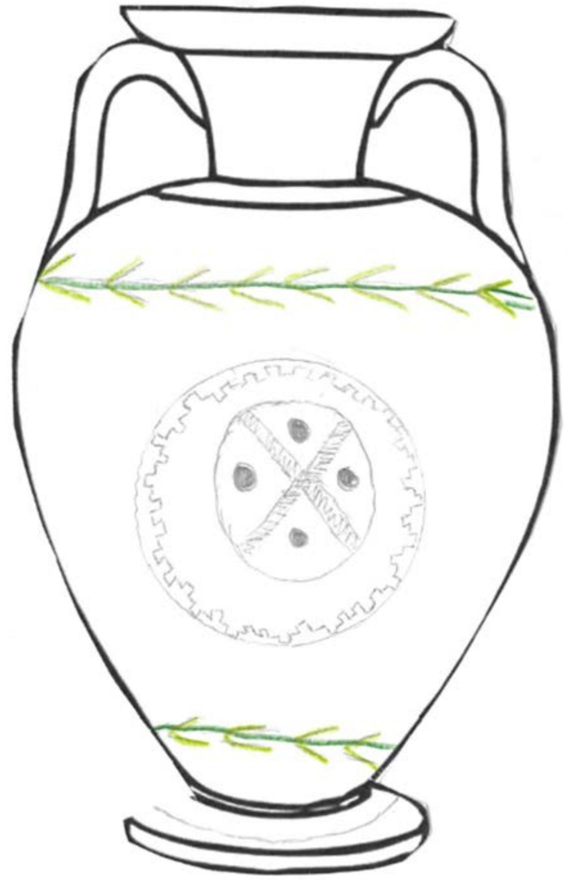


> *"This is really what I had in mind. I was thinking of the Roman soldier colours. I was going for red and silver."*
>
> - Alexander

> *"I like patterns because it explains a story. [The soldiers] explain the story of how gladiators were fighting in the colosseum.*
>
> - Evelyn

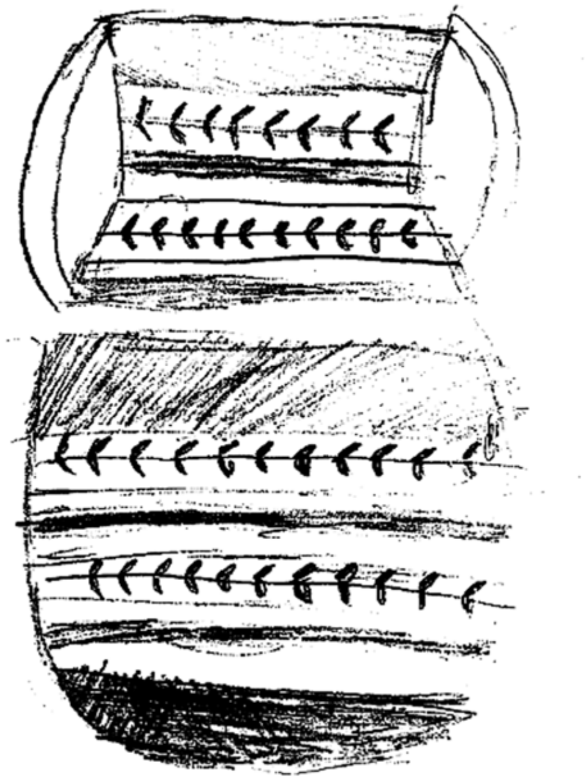
Figure 10. Examples of students' sample drawing, writing and their corresponding virtual reality Roman vessels. In this instance, students experimented with Roman pottery design and creation using VR.

Figure 11. This example shows student painted artwork, both inside and outside of their virtual vessel.



CONNECTING NEW KNOWLEDGE WITH PAST EXPERIENCES

As noted in this component of our study, in virtual reality learning studies, researchers have observed the significance of children's prior physical interactions with objects when they encounter new virtual materials (Søyland, 2020). The multiliteracies pedagogy of the New London Group (2000) emphasises the connection between new knowledge and past experiences. This connection is fostered through real-world activities where learners engage with both familiar and novel elements (Mills, Brown & Funnell, under review). This process ultimately leads to transformed practice, enabling students to create unique multimodal texts (see also Cope & Kalantzis, 2015).



Outcomes with Mixed Reality Technology

The primary focus of research on augmented reality (AR), virtual reality (VR), and mixed reality (MR) in education has predominantly centred around students' consumption of educational content. However, our research has shifted the focus to acknowledge the importance of students creating narratives rather than merely receiving them, particularly transmedia narratives or storytelling across various mediums or technologies. In this component of the study, students brought stories to life using the Microsoft Smart Glasses HoloLens 2™. This was achieved by transforming their written stories into digital versions—incorporating visuals, videos, and audio elements, including 3D holograms—resulting in a more captivating experience. Mills and Brown (2023, p. 3) explored two key research questions: "(i) How can smart glasses support students' multimodal composition in the classroom? (ii) What multimodal resources are available to students wearing smart glasses to compose narratives?". Below is a summary of key themes that emerged.

Blending the virtual and real world with smart glasses

During the creation of the smart glasses story, the students' interactions between the virtual and real worlds were documented. Notably, the holograms responded to the students' hand motions directly, without the need for intermediary devices like game controllers. This direct interaction led the students to perceive and experience the holograms as genuine and authentic. The virtual texts in the form of sound effects and still and animated images provided different ways for students to interact with their surroundings in the classroom. These virtual elements appeared to be floating in the air and could be controlled by students through their hand movements, gaze, and voices.

Students made use of the various options available in these multimodal texts, adjusting their storytelling skills to fit this new context. The blending of the real and the virtual was a unique feature of this textual practice, and the holographic stories had a greater connection to an actual place in the real world. Furthermore, the smart glasses supported interactions between realities. Specifically, that the virtual texts responded to the users' real movement in an actual physical location, with both co-present and visible class members (Mills & Brown, 2023).

In-air haptics and story composition

The students used haptic gestures to interact with the 3D virtual objects while composing their stories. They employed gestures like grabbing (pinching, closing their hand, dragging, and releasing) and pointing (touching, scrolling). The HoloLens 2™ device is designed with a haptic gesture cues or recognition system, allowing users to manipulate 3D virtual models through hand movements. The research team noted that the students found these haptic gestures instinctive and natural (Mills & Brown, 2023). Examples of in-air haptics can be seen in Figure 12.3D visual mode and conveying meaning

During the narration of holographic stories using smart glasses, the visual mode played a crucial role in conveying meaning. The task involved overlaying different static and animated 3D models to establish settings, depict characters, and indicate key events using significant objects, accompanied by audio-recorded narration. The students utilised 3D holographic models to capture the audience's visual focus on the story's setting, important characters, and significant story moments. The inclusion of animated holograms contributed to the immersive and vibrant portrayal of the stories (Mills & Brown, 2023).

Comparisons and new ways of writing and telling stories with MR

As Mills and Brown (2023) noted, one of the goals of exploring the possibilities of using smart glasses for multimodal composition was to examine how students' previous school experiences in narrative creation could be compared. In addition to analysing the students' transmedia stories created through drawing, writing, and storytelling with smart glasses, researchers also prompted the students to draw comparisons with other story-making activities they had engaged in at school. Regarding similarities, the students observed that regardless of the new media involved, the core of the activity remained rooted in the art of storytelling. When asked about the distinctions in crafting stories across various media, students highlighted the increased level of interactivity provided by the blended technology (Mills & Brown, 2023).

Our research on smart glasses was guided by recognising that students are not just consumers of learning material but are also creators. The technology used during these research activities has provided a new perspective on how students can create and tell their own stories in unexpected ways. As such, this leads us to think of how augmented reality may play a role in reading and comprehension in addition to reading and writing and story creation explored in this section.

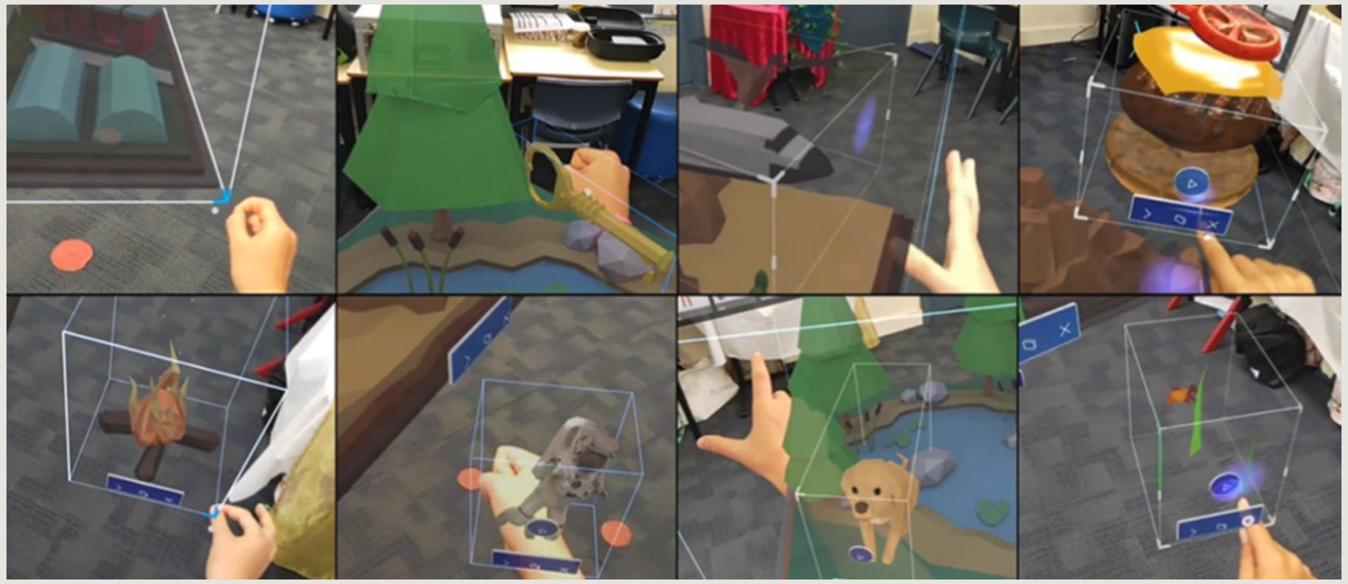


Figure 12. Examples of in-air haptics in a mixed reality environment where students can be seen to pinch, grab, and scroll within the MR environment.

Outcomes for Augmented Reality

We investigated the role of AR in reading and comprehension to see how such technology engaged students in relation to multimodality and learning. Students in the component of the study ranged in age from 11-16 years of age (grades 6-10). A summary of this research is provided below.

BACKGROUND

A growing body of research indicates that students exhibit better engagement with reading when utilising augmented reality (AR) as compared to traditional books. For example, Cheng (2017) highlights the capacity of AR book systems to bridge the gap between physical and virtual objects, thereby enhancing readers' comprehension of book content, particularly abstract concepts that are challenging to grasp. He also explores the concept of 'cognitive load' in AR reading contexts, stating that students do not need to exert significant mental capacity or effort in processing information within AR books.

Augmented reality (AR) technology offers several advantages in the field of education. A systematic review conducted by Akçayır and Akçayır (2017) suggests that AR promotes enhanced learning achievement, increases student motivation, improves investigation skills, and enables authentic explorations in the real world. Furthermore, a quantitative analysis of data from a review by Garzón et al. (2019) indicates that AR has a medium impact on learning effectiveness. Notably, the most commonly reported advantage of using AR in education is that students demonstrate faster and easier learning when utilizing AR applications compared to non-AR applications.

Reading and comprehension with AR

During the fieldwork component of this research, the team explored two popular AR apps, that could be easily and freely accessed and used with iPads. The first of these was the AR Makr app (https://apps.apple.com/us/app/ar-makr/id1434081130) that allowed students to sketch and scan images and take photographs, transform those images into 2D and 3D virtual objects and then, using the creative toolbox for augmented reality, anchor those creations anywhere within their own environment. They could also add commentary or narration. The result could then be recorded, saved, and shared. The AR Makr app on the iPads provided a complementary activity—students selected a scene from a story previously written in class could and could enhance it by creating a multimodal composition (see Figure 13).

Figure 13. A student finding a virtual 'anchor' point with AR Makr to set the scene for their story.

Images used in AR Makr could be drawn from a variety of sources—taken on the iPad's camera, hand-drawn within the app, sourced online and saved, or imported from digital cameras (photographs were taken as part of a corresponding activity with Big Picture Industries, as described in the Digital Imagery section of this report). Students could then narrate the scene via the app, tapping into various senses and layers of storytelling.

Some of our older students (grades 9-10, aged between 14-16 years) worked with the second AR app. This activity used a Merge Cube™—a physical foam rubber cube, about the size of a tennis ball—that provides an anchor point for the 3D visuals of the associated app, Explorer™. The Merge Cube™ allows students to 'hold' digital 3D objects. The cube provides an innovative way to interact and learn within a digital world. An example of a Merge Cube™ can be seen below in Figure 14, in addition to a sample of the 3D images from one of the many educational based activities available on the Explorer™ app.

The Merge Explorer™ app provides many education-based activities, ranging from 'Galactic Explorer' and a 'Ticket to Mars' to learning about frogs, and related reptilian anatomy through a virtual dissection. The example in Figure 15 shows the annotated labels of the Mars Rover, where students moved and rotated the cube to see all sides and perspectives of the rover. Each activity has an overview of information, and then allows students to tap in to read related information projected on the cube. After the students have completed their exploration of the various items, a quiz is available to check for understanding and their comprehension of the content covered in the AR module.

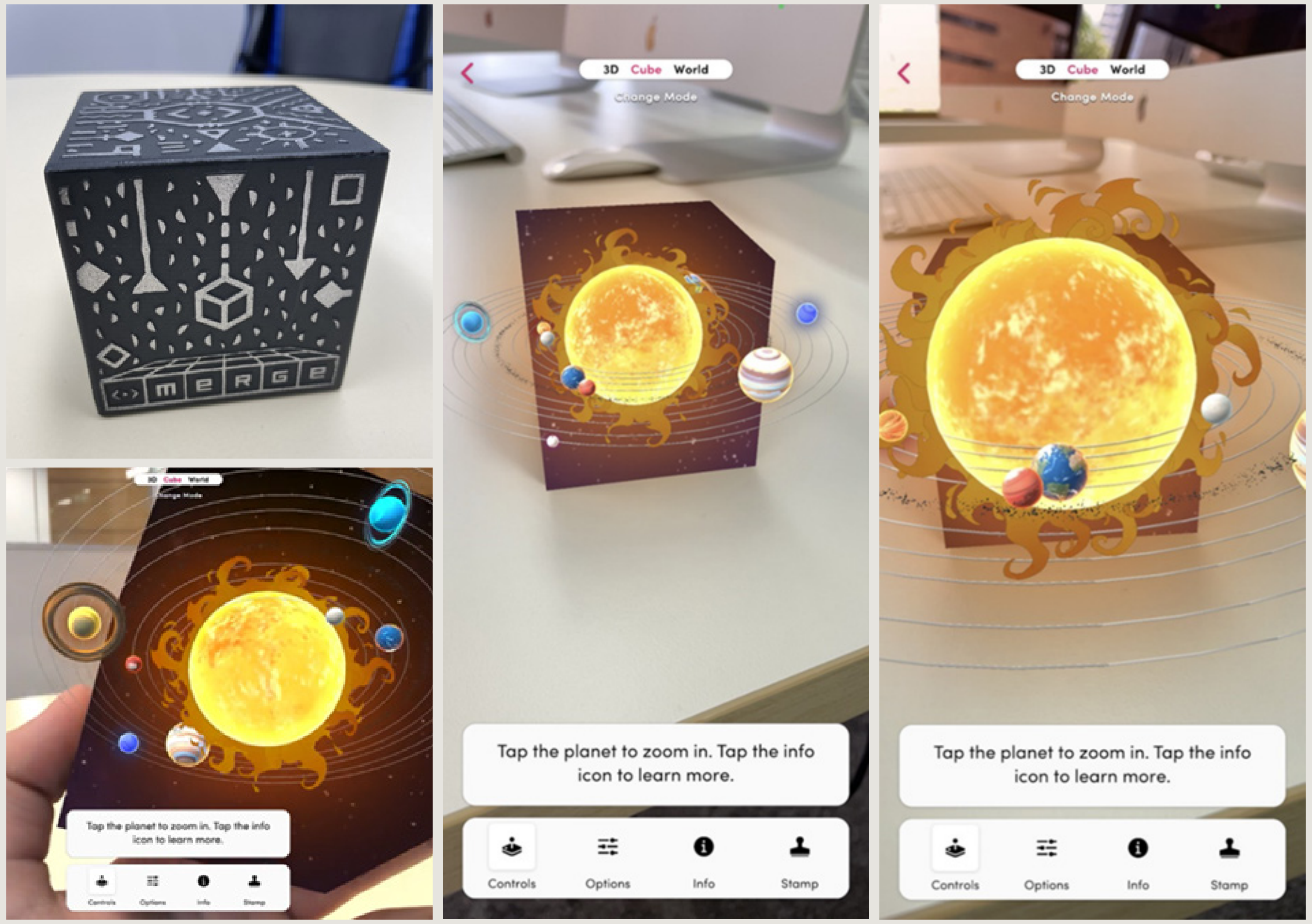


Figure 14. The physical Merge Cube™ (top left) and the images depicting the AR overlay, when viewed on an iPad through the Explorer™ app. The lower left panel shows a student holding and rotating the cube to view multiple perspectives of the solar system. The solar system is also animated, demonstrating the rotation of the planets around the sun.

Students can touch, move, and rotate the physical cube and enlarge or shrink the AR overlay projections via the iPad app. Additionally, given the tangible nature of the cube, it allows students to also move the cube physically to 'zoom in' or out. Such touch and manipulation align with our earlier observations and analysis, including our work in makerspaces (Friend & Mills, 2021), and the use of haptics and other sensorial and bodily interactions with digital texts in VR and MR contexts (Mills, Scholes, & Brown, 2022; Mills & Exley, 2023; Mills & Brown, 2023).

Merge EDU is a purpose-built education AR app and resource in that structured lesson plans and activities are provided for classroom teachers or other educators to use, rather than having to create their own plans. Other Merge Cube™ compatible apps are also available and lesson plans can be created from scratch depending on classroom and curriculum needs. The Merge Cube™ website provides access to resources and there is a Facebook-based community of practice (Lave, 1991; Wenger, 1998). The lesson plans and materials are available for subscribers to the app and are free for short trial periods. Many activities align with existing school and classroom curriculum.

It should also be noted that within this research, the two AR apps served different purposes. The AR Makr allowed for story or narrative creation (e.g., such a recreating a virtual scene from a student's written story), whereas the Merge Cube™ app was aimed primarily at reading and comprehension.

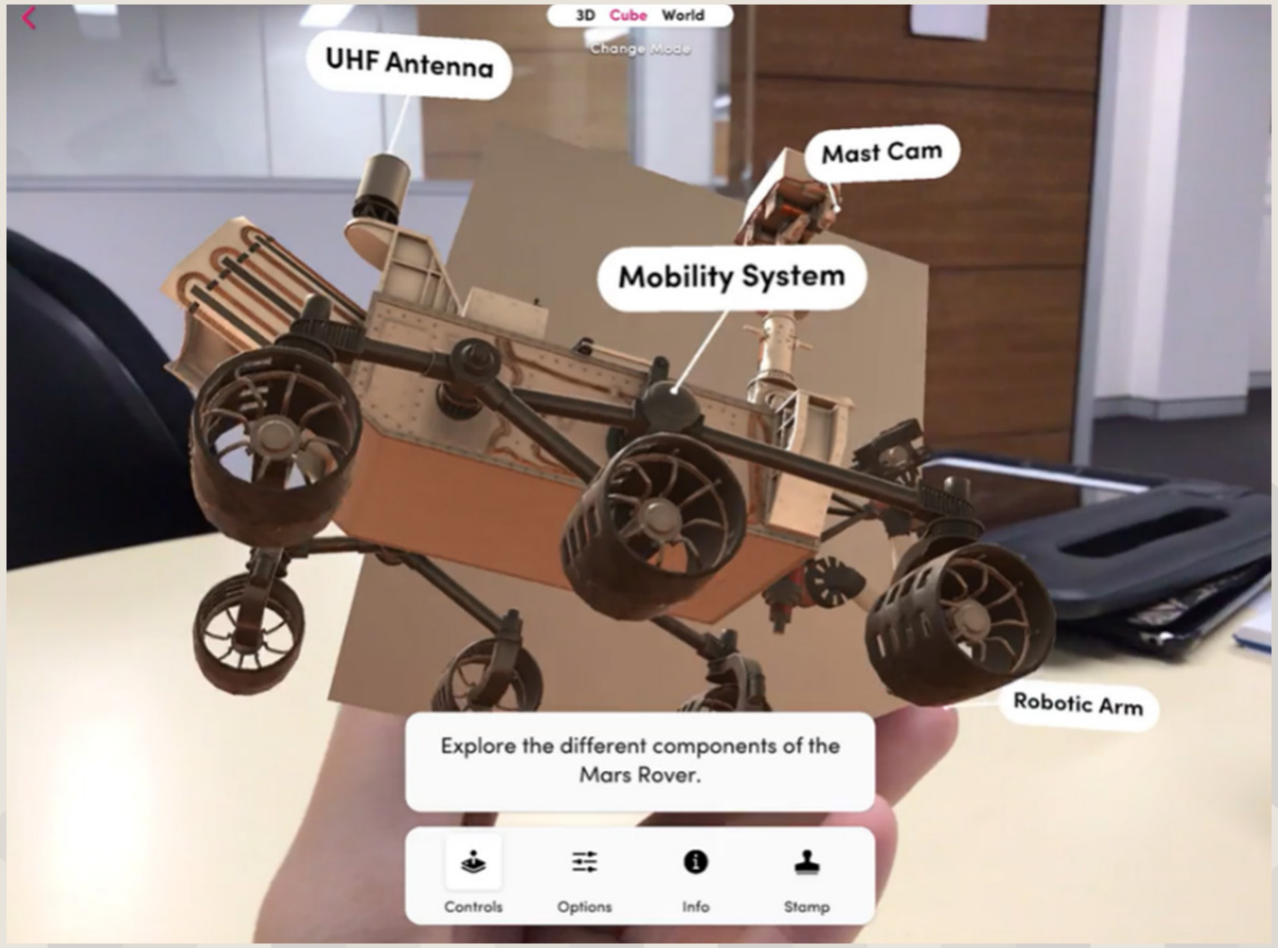


Figure 15. An overview of some of the components of the Mars Rover from the Merge Explorer™ app.

The senses, transmediation and comparison between AR Makr and Merge Explorer ™

The fieldwork also allowed researchers the opportunity to compare the different ways in which students interacted and engaged with each AR app, and some comparisons can be made between the AR Makr and the Merge Cube™ with its Explorer™ app. AR Makr provided an opportunity for students to place their selected images to create three dimensional objects. They could then move the iPad around the scene they had created to give an impression of depth and movement and zoom in out of the scene to enlarge their drawings and change the perspective. The students could accompany these scenes with narration recorded directly onto the iPad and into the app.

Some students had difficulty pinning down an anchor point for the AR overlay, but used this experience to problem solve and rework their story scene in situ, providing natural and spontaneous story narration. Other students, who had previously struggled with writing, were amazed with what they could create in AR Maker. They were happy with their ability to transmediate the story in and across another mode. By comparison, the Merge Cube™ allowed the students the opportunity to hold, turn, and rotate the overlayed 3D models, to engage another sense—the tangibility of touch and texture. On the iPad, students could also pinch to shrink and enlarge the visual overlays they could see on screen, tapping into the notion of explorative touch.

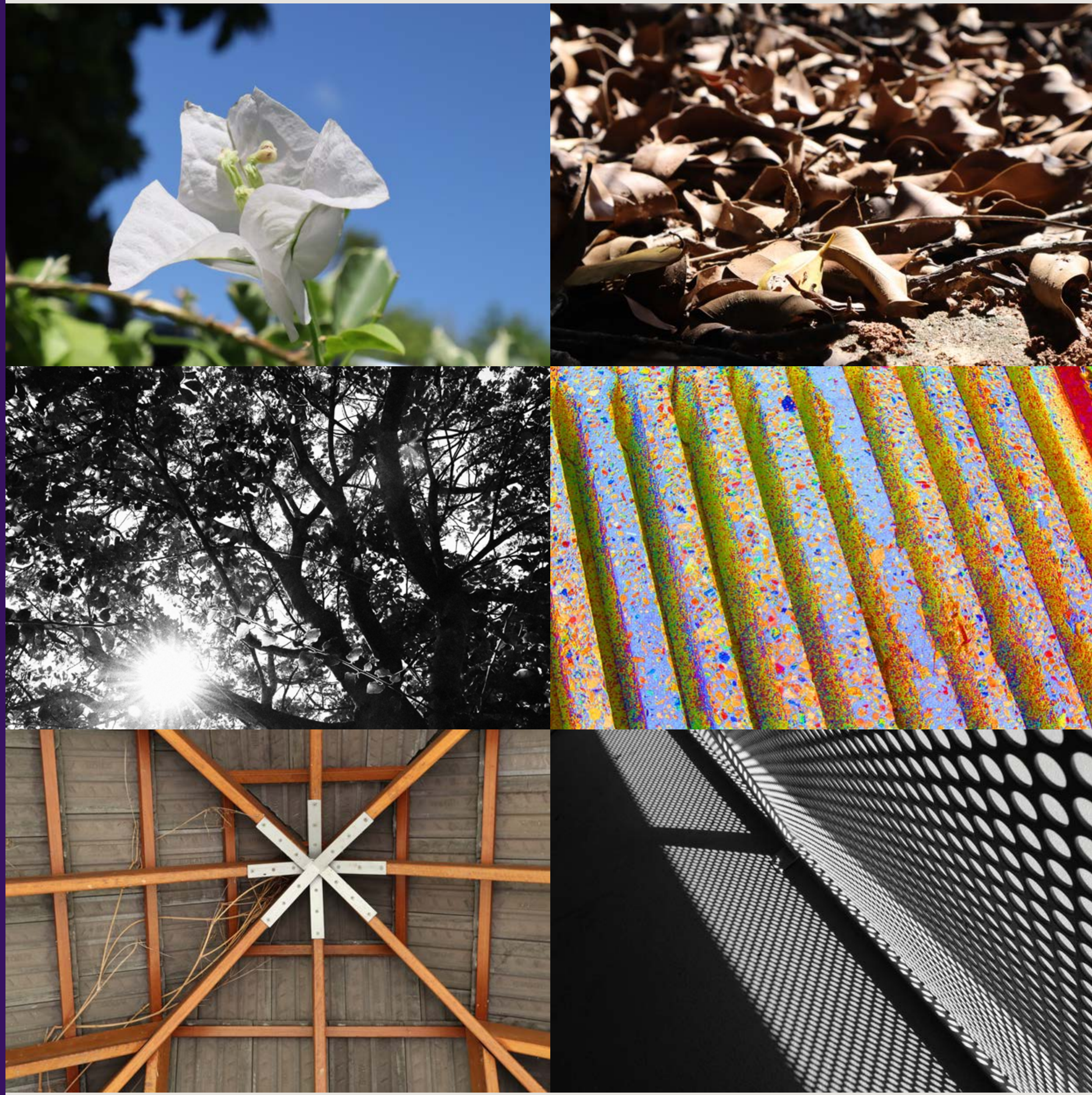
The Merge Cube provided a reliable and consistent surface on which to 'project' or 'anchor' the 3D overlay, with the added benefit of allowing the 3D images to be moved, rotated, and manipulated by the students. Students could also 'zoom in' and enlarge overlay imagery via the iPad whilst holding the cube. This section of the research work explored how students could explore reading and comprehension through sensory and augmented means, providing unexpected learning and sensory experiences.

Outcomes for Digital Imagery

Interwoven with our work in augmented reality, and in partnership with Mark Williamson of Big Picture Industries, students explored digital photography to create and manipulate imagery.

This provided an opportunity for authentic learning contexts, as students focused attention on their surroundings and learnt about elements of design and art in photography using DSLR cameras and iPads. Over the course of the project, students worked on various digital imagery and photography activities. The student images in Figure 16 illustrate colour, texture, line, pattern, shadow, and the rule of thirds.

Figure 16. A sample of some of the photographs taken by students over the course of the project (opposite).



In one activity, students worked with DSLR photography to complement a corresponding unit in visual arts with a focus on textiles and weaving. Students could creatively apply the principles of textile weaving and experiment with photography tricks to create similar 'woven' images. This allowed students to look at patterns across texts and consider how the medium employed had changed the tangibility of the text (Harris, 2021).

In another workshop, student curiosity was encouraged through student-centric, experiential learning outside the classroom that ran parallel to the VR activities and would become of their story scene creation in augmented reality. As seen in Figure 17 below, a student uses an iPad to photograph various textures and elements of nearby parkland.

Figure 17. A student ventures around the neighbouring parkland using an iPad to take images of their surroundings.

At the conclusion of the activity session, the students reflected upon and critiqued their images to consider how and what they created, and the meanings incorporated into their visual and digital photographs. Some of these digital images were integrated into the students' AR Makr story scenes, as described earlier in the Augmented Reality section of this report.

In yet another activity, students played with the sense of perspective, and manipulated solid objects to alter proportion to make small dinosaur figurines appear large and intimidating. The students then compared these to AR digital images that could be overlayed in a scene to see how the visual impression of size worked virtually. See Figure 18.

These images exemplify how digital photographic techniques can be employed within AR to combine images, exaggerate size, employ close ups, and playfully manipulate perspective and proportion. This activity provided opportunities for students to think creatively about images and delve into a whole new perspective on framing and composition, and as consumers of digital imagery, to think critically about how images could be created and manipulated.

Figure 18. Student created images using AR to create perspective and another example using physical objects combined with photographic techniques to create an illusion of size.

Implications for School Leaders and Teachers

While many teachers do not yet have access to a wide variety of technology, VR, AR, and MR are rapidly increasing in use in both consumer and educational contexts. As a result, schools need to be prepared for these fast-growing technologies as they become more affordable and accessible.

The research outlined in this report suggests many possibilities for schools and teachers to explore the innovative role of emerging immersive and hybrid technologies, in addition to makerspaces, and how these align to sensory concepts in multimodal literacy learning. It should be noted that multimodal technologies and their affordances are already recognised within school curricula. For example, the word 'multimodal' appears 311 times in the Preparatory to Year 12 Australian Curriculum (ACARA, 2023b), spanning subject areas including English and other language learning areas as well as across the general capabilities of critical and creative thinking, digital literacy, ethical understanding, and literacy (ACARA, 2023a).

MAKERSPACES

When schools or teachers consider makerspaces for incorporating multimodality into student learning experiences, several implications arise. Below are recommendations for teachers and schools for incorporating makerspaces, that also incorporates foley spaces for sound effects and audio creation.

- **Promoting innovation and creativity in multimodal design:** Makerspaces encourage students to think creatively and develop innovative solutions to problems. As noted in our report, makerspaces also allow students to engage in sensory multimodal practices and enhance literacy learning through the senses in unexpected and creative ways (Friend & Mills, 2021). Teachers can foster an environment that nurtures students' imagination, critical thinking, and problem-solving skills, and can approach this from a sensorial perspective.

- **Integrating multiple disciplines through multimodal literacy:** Teachers can create opportunities for cross-curricular connections, helping students see the relevance of different disciplines and encouraging them to apply knowledge and skills from diverse learning areas. Our research showed that young participants successfully engage in a variety of activities across disciplines from technologies and sciences to the arts and English, as evidenced by the creation of e-sculptures and the use of electronic Arduino™ Kits.

- **Student collaboration and communication in multimodal making:** Makerspaces promote student collaboration and teamwork. Teachers can encourage a culture of sharing and effective communication among students. To do so, they may need to facilitate group projects, establish procedures for teamwork, and encourage students to exchange ideas, provide feedback, and collaboratively problem solve.

- **Technology integration with English and the arts:** Makerspaces often involve the use of technology tools, such as those involved in digital media, electronics kits, audio, and technical components. Teachers need to be comfortable with these technologies themselves and be prepared to assist students in their use or have available technical support. This was found in our activities undertaken using the Arduino™ Kits in the various makerspace activities at the Toledo Museum of Art. Teachers may need to familiarise themselves with such new tools and stay up to date with emerging technologies.

- **Teacher professional learning and development in multimodal literacy:** Teachers may require professional learning and development opportunities to enhance their understanding of makerspaces, learn new technologies, and develop strategies to integrate these effectively into the curriculum. Engaging with local libraries, galleries, and museums (such as QAGOMA) may be helpful, in addition to various professional subject area/teacher associations (e.g., Australian Association for the Teaching of English [AATE], Australian Literacy Educators Association [ALEA], Australian Teachers of Media [ATOM], Australian Library and Information Association [ALIA], Primary English Teachers Association Australia [PETAA]) and ACARA's new professional learning hub (https://learning.acara.edu.au).

AUGMENTED REALITY (AR), VIRTUAL REALITY (VR), AND MIXED REALITY (MR)

Research shows that when teachers are asked if they would use AR, VR, and MR, the majority would love to explore this technology (Almufarreh, 2023; Khukalenko et al., 2022; Marín-Díaz & Sampedro-Requena, 2023; Mills & Brown, 2023; Southgate, 2023). There are new pedagogical advantages for learning:

- **Multimodal pedagogical adaptation:** As noted in the outcomes of this larger study, AR, VR, and MR technologies provide opportunities to explore new ways to deliver multimodal literacy content and to facilitate student engagement. Even where a learning task appears to only require the students' straightforward replication of information, such as when re-telling a story in a different mode, translating this knowledge becomes a generative process, as evidenced when students told Greek myths through virtual painting.

- **Technological competence and proficiency:** Teachers can learn to develop a level of technological competence and proficiency in working with AR, VR, and MR for multimodal literacy, to confidently provide guidance and support to students and to maximise such technologies' potential for educational purposes. Proficiency is attained through appropriate professional learning and development experiences and collaboration with industry, in addition to technical support and assistance from the school.

- **Content and app selection and curation:** Teachers should select, curate, or design appropriate AR, VR, and MR content that aligns with their teaching and curriculum objectives. Available resources should be evaluated to design activities to meet curriculum standards, and to generate appropriate and relevant educational learning experiences for unique learning contexts.

- **Student engagement and motivation for literacy learning:** As noted in this research, AR, VR, and MR can enhance student engagement and motivation by providing augmented, immersive, and interactive experiences. Such technologies can provide students with different approaches and perspectives in their literacy learning. We would encourage teachers to actively involve students in co-designing learning experiences, and to maintain a balance between exploration and conventional modes of literacy learning. It is important to note from our research that students are seen as producers and not just consumers of media.

- **Classroom management with 3D technologies:** Managing an AR, VR, or MR classroom requires thoughtful and considered planning. It is important for teachers to ensure that students understand the physical boundaries of virtual and augmented environments, respect each other's physical space, and use technology responsibly. Most educational games can be offered to students offline, so the content is presented in a safe digital learning environment. It is recommended that teachers be prepared to provide guidance during immersive experiences, address technical challenges, and monitor student progress.

- **Equity, accessibility, and ethical considerations:** As with other digital technologies, teachers will need to consider equity and accessibility to ensure all students have equal access to the required devices and resources when participating with AR, VR, and MR in the classroom, irrespective of students' socioeconomic background or abilities. Connected with this, it is important that teachers and schools address associated ethical considerations including responsible use and protection of individual student privacy when working with such immersive and augmented technologies.

It is important for teachers to approach these technologies for multimodal literacy learning with thoughtful planning, ongoing professional learning and development, and with a focus on aligning technology use with curriculum objectives.

DIGITAL IMAGERY

The use of digital imagery in school classrooms can provide many opportunities for teachers and students. Such imagery can support multimodal and written learning experiences. We have listed some key considerations below:

- **Visual prompts in multimodal literacy:** When teachers incorporate 2D and 3D digital imagery, including photography, literacy learning experiences for students are enhanced. Teachers can use augmented reality images and conventional photography to illustrate ideas, demonstrate processes, and stimulate discussions through hand-on learning and movement by walking with the camera. Students can also compose written descriptions of images they find and create and extend their descriptive writing skills.

- **Creativity and expression in multimodal literacy with 2D and 3D imagery:** As noted in our research, using digital imagery and conventional photography offers students opportunities for creative expression. Teachers can encourage students to capture and manipulate images, supporting their artistic skills and imagination. Such imagery can also be combined with augmented and immersive technologies, such as those used in story scene creation in *AR Makr*.

- **Authentic sensorial learning:** By using digital imagery and photography, students can document their learning in a multimodal capacity whether in class or on excursions to educational sites. Students can showcase their work and accompany images with written reflections on their learning experiences.

- **Critical and creative literacies:** Teachers can help students develop critical and creative literacies in addition to digital literacy skills (see also ACARA, 2023a) by analysing and interpreting images and photographs they find online or create themselves. Students can learn to critique and evaluate visual content for bias, symbolism, composition, and manipulation. This develops critical thinking skills and enables students to understand and navigate the visual information they encounter in the digital age.

- **Multimodal storytelling:** Teachers can guide students on how to select, edit, and attribute images appropriately to enhance their written communication and storytelling skills. The addition of such multimodal elements can enrich student presentations and projects.

- **Ethical use and copyright considerations:** Teachers should also help students understand the ethical considerations in respect of the intellectual property rights associated with the creation and manipulation of digital imagery and photography and guide them in the appropriate and responsible use of copyright/royalty-free or Creative Commons-licensed materials (https://creativecommons.org). They can encourage students to consider ethical issues in the creation of their own digital images and photographs. This also contributes to meeting the general capability of 'ethical understanding' (ACARA, 2023a).

COLLABORATION WITH INDUSTRY

Our research partnerships with Big Picture Industries, The Toledo Museum of Art, Queensland Art Gallery/Gallery of Modern Art (QAGOMA), and The Drama Merchant demonstrated the many potentials of industry collaborations with schools, and those involved in educational innovation. As such, some of these potentials are outlined below:

- **Industry expertise:** Collaboration with external organisations may provide resources, such as expertise, equipment, and tools to support the development of innovative learning experiences between school, research, and industry.

- **Workshops and guest speakers:** Schools can invite professionals from external organisations and industry to give guest lectures or facilitate workshops. As noted in our research with Big Picture Industries (CEO Mark Williamson) and The Drama Merchant (CEO Nathan Schulz), industry professionals can share their knowledge and experiences, and play a role in exploring multimodality that can contribute to building on school-wide literacy learning. Engagement with external industry professionals and researchers is also beneficial to teachers and for staff the professional learning and development of school personnel.

- **External support for curriculum and professional development:** Schools can collaborate with technology specialists, literacy researchers, and media industry professionals to develop curriculum materials and resources. Engaging such professionals can provide skills, current industry knowledge, and access to various tools and equipment. Schools can also organise professional development workshops, by inviting researchers and industry professionals and representatives from professional subject area associations, to share their expertise with teachers.

- **School and university research:** Schools can engage in research collaborations with industry professionals and university researchers. These partnerships can involve joint research projects or explore the use of emerging technologies and practice in educational contexts in literacy learning. As indicated by this research work, collaborative research can lead to the development of new insights on multimodal and literacy learning that benefit both the education sector and beyond.

- **Community engagement and events:** Schools can host events such as exhibitions or innovation showcases. These events can attract industry professionals and researchers to connect with students, share their work, and inspire future makers and creators.

External collaborations can prepare students for future careers and encourage a culture of innovation in education. It allows schools to provide unique and exciting learning experiences for their students. Such opportunities also provide relevant professional learning and development for school leaders, teachers, and education support staff.

Conclusion

The hybrid technologies and concepts discussed in this report (VR, AR, MR, makerspaces, and digital imagery) have become more widely available and less expensive, since the development of wearable, head-mounted displays, and apps and devices that provide users with various multimedia that simulate a physical presence in a virtual, three-dimensional, or augmented environment.

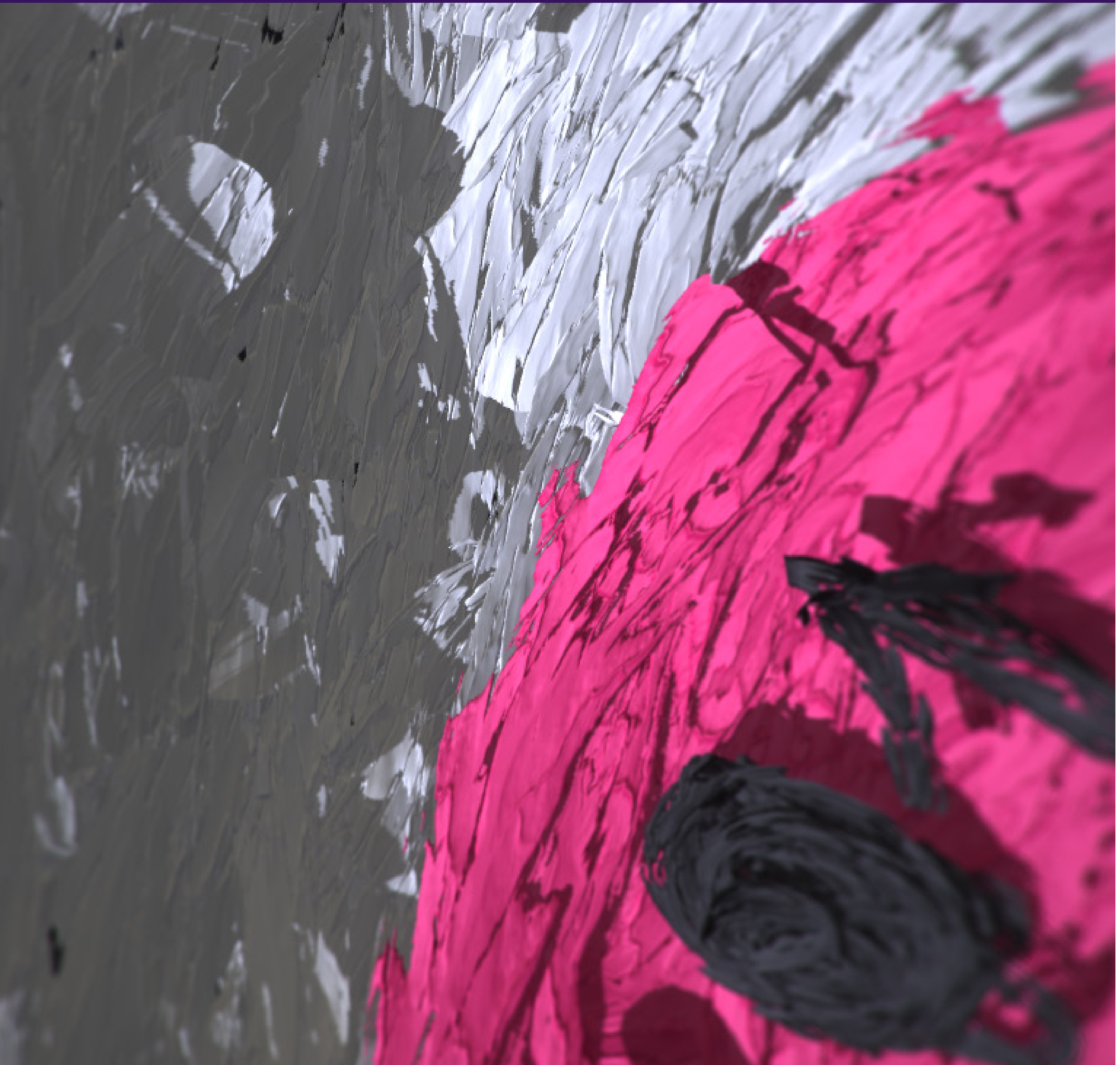
The rapid progress of these technologies, along with their application in literacy education, presents exciting opportunities for conveying meaning across different media. There is vast potential yet to be explored in translating narrative content into visual, tactile, and sensory formats within the realm of hybrid technology and media design.

For schools and teachers, VR, AR, and MR technologies, in addition to makerspaces, have the capacity to support a wide range of pedagogies, with benefits for experiential and contextual learning and applied knowledge. Such technology can be utilised to promote knowledge translation across sign-making or literacy systems, by exploring the role of the senses in multimodal literacy learning and embodied cognition (Mills, Unsworth, & Scholes, 2022). This translation includes even the reproduction of the simplest task learned through drawing, listening, and writing, and the act of transferring this knowledge into a new modality. It is not just straightforward replication of content, but rather the lack of equivalence between modes which encourages learners to participate in a dynamic process of adaptation and knowledge transformation (Mills, 2011). Learners must recast their knowledge through the more sophisticated, multimodal, immersive, and interactive, yet physically intangible, three-dimensional expression planes that are now used in education.

These hybrid technologies provide opportunities for young people to encounter virtual scenarios that are inaccessible in the real world (in time and space), providing a learning advantage which has foreseeable benefits for investigating story worlds (Mills, 2022). More critically for multimodal literacy development, recent research with school-aged students has shown new potential for transmediation and embodiment when utilising virtual reality (Mills & Brown, 2022; Mills, Scholes, & Brown, 2022).

We encourage further reading of the research outlined in this report. We have provided a section of publications that have emerged from this research which will be useful for education and industry professionals interested in professional development, curriculum integration, and learning innovation.

Project Publications



Numerous publications emerged from the project. In order of recency of publication, these are:

Mills, K.A. (2023/24, in press). What Counts as Language learning in a born-digital textual world? In Ludwig, C. & Kersten, S. (Eds). Born Digital Texts in Language Learning and Teaching. Multilingual Matters.

Mills, K. A., Brown, A., & Funnell, P. (Under review). Virtual reality gaming as 3d multimodal designing. *The Australian Education Researcher.*

Mills, K. A., & Exley, B. (2023). Sensory literacies: The full sensorium in literacy learning. *International Encyclopedia of Education: Volume 10 Literacies and Languages*. (4th ed., pp. 480–486). Elsevier.

Mills, K. A., & Brown, A. (2023). Smart glasses for 3D multimodal composition. *Learning Media & Technology*, 1-22. [Published first online]. http://dx.doi.org/10.1080/17439884.2023.2207142

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Mills, K. A., & Brown, A. (2022). Immersive virtual reality (VR) for digital media making: transmediation is key. *Learning, Media, and Technology*, 47(2), 179-200. https://doi.org/10.1080/17439884.2021.1952428

Mills, K. A., Scholes, L., & Brown, A. (2022). Virtual reality and embodiment in multimodal meaning making. *Written Communication*, 39(3), 335-369. https://doi.org/10.1177/0741088322108

Mills, K.A. & Exley, B. (2022). Sensory Literacies: The Full Sensorium in Literacy Learning. In Yaden, D. & Rogers, T. Literacies and Language Education, International Encyclopedia of Education, 4th Edition

Mills, K. A., Unsworth, L., & Scholes, L. (2022). *Literacy for digital futures: Mind, body, text*. Taylor & Francis. https://doi.org/10.4324/9781003137368

Friend, L., & Mills, K. A. (2021). Towards a typology of touch in multisensory makerspaces. *Learning, Media and Technology*, 46(4), 465-482. https://doi.org/10.1080/17439884.2021.1928695

Friend, L. & Mills, K.A. (2021). Researching children's virtual reality. In Serafini, F. (Ed.) Beyond the Visual: Researching Multimodal Phenomena. Teachers College Press. https://www.tcpress.com/beyond-thevisual-9780807766842

RECOMMENDED PUBLICATIONS FOR FURTHER READING

Several additional academic papers, related to the work on this project by the authors, but not funded from this project, have been published. In order of recency of publication, these are:

Gutierrez, A., Mills, K., Scholes, L., Rowe, L., & Pink, E. (2023). What do secondary teachers think about digital games for learning: Stupid fixation or the future of education?. *Teaching and Teacher Education*, 133, 104278.

Baker, B., Mills, K. A., McDonald, P., & Wang, L. (2023). AI, concepts of intelligence, and chatbots: The "Figure of Man," the rise of emotion, and future visions of education. *Teachers College Record*, 125(6), 60–84. https://doi.org/10.1177/01614681231191291

Moro, C., Mills, K. A., Phelps, C., & Birt, J. (2023). The Triple-S framework: Ensuring scalable, sustainable, and serviceable practices in educational technology. *International Journal of Educational Technology in Higher Education, 20*(7). https://doi.org/10.1186/s41239-022-00378-y

Scholes, L., Rowe, L, Mills, K. A., Gutierrez A., & Pink, E. (2022). Video gaming and digital competence among elementary school students, *Learning, Media and Technology*, 1–16. [Published first online]. https://doi.org/10.1080/17439884.2022.2156537

Scholes, L., Mills, K. A. and Wallace, E. (2021). Boys' gaming identities and opportunities for learning. *Learning, Media and Technology*, 47(2), 163–178. https://doi.org/10.1080/17439884.2021.1936017

Mills, K.A. & Rowe, L. (2024, in press). Quality in Big Qualitative Research. In Flick, U. *Sage Handbook of Qualitative Research Quality*. Sage.

Mills, K.A. (2023). Intellectual tributaries of the digital turn in literacy Studies. In Avila, J. (Ed.). Leaders in English Language Arts Educational Studies: Intellectual Self-Portraits. Brill

Mills, K.A. (2022). Big Data in Qualitative Research. In Atkinson, P. (Ed.) Sage Research Methods Foundations. SAGE.

Friend, L. & Mills, K.A. (2021). Researching children's virtual reality. In Serafini, F. (Ed.) Beyond the Visual: Researching Multimodal Phenomena. Teachers College Press. https://www.tcpress.com/beyond-thevisual-9780807766842

Media and Invited Keynote Presentations

MEDIA

Professor Mills engages with national and international literacy curriculum debates, as evidenced by:

Henebery, B. (2023, June 2). Exclusive: New wearable 3D tech supercharging student engagement. *The Educator Australia*. https://www.theeducatoronline.com/k12/news/exclusive-new-wearable-3d-tech-supercharging-student-engagement/282586

Moro, C., & Mills, K. (2019, February 19). Technology and learning in the classroom: six tips to get the balance right. *The Conversation*. https://theconversation.com/technology-and-learning-in-the-classroom-six-tips-to-get-the-balance-right-111430

In addition to news media cited above, ACU pitched her journal article findings on virtual reality and the senses to news media, which was covered by News Corp print and online papers across Australia (22/04/22). She was interviewed with James Gee on writing in a digital age for U.S. news channel Against the Grain (07/05/19) and published on technology tips for the classroom in The Conversation (19/02/19). She conducted an ABC South-East NSW radio interview on the benefits of playing Minecraft at school (14/7/15). Professor Mills' research findings about high stakes testing and NAPLAN led to invited national TV and radio broadcasts on ABC radio Alice Springs (02/20).

INTERNATIONAL AND NATIONAL PRESENTATIONS

During the project Professor Mills gave four invited keynote addresses via online conferences to researchers in Germany, Cyprus, and Australia (see below) during Covid. This year, Mills gave another four international keynotes and three presentations in Italy (Contemporary Humanism International PhD Program); Mexico (Seminar on Innovation for Educational Leadership and Literacy); the UK (ReMap: research in Media Arts and Play, UCL), Sheffield Hallam University; and Norway, (USN, Notodden).

International

- Professor Kathy Mills was invited to present from the Senses Together project on The Future of the Digital Turn in the New Literacy Studies at del Instituto Transdisciplinar en Literacidad (Guadalajara, Mexico). At the University Centre of Art, Architecture and Design (CUAAD) on June 12th, 2023.
- Professor Mills presented on the future of digital practices in literacy as keynote with honorarium, for the Digital Symposium: Friedrich-Alexander-University, Erlangen-Nurnberg Germany (2022, March 31).
- 4th International Conference Literacy and Contemporary Society, Cyprus (2021, March 12–13). Mills' presentation on Transmediation using Virtual Reality Technology was received by over 400 international delegates in the live online meeting, with live translations into four languages.
- Westfälische Wilhelms-University of Münster (2020, March 5). Mills' presentation with honorarium led to an invited journal article for German-English readers on technologies, gaming, and language learning.
- Invited keynote Presentation (in person and hybrid mode): Professor Mills presented Smart Glasses for 3D Multimodal Design, Knowledge Lab and Research in Media Arts and Play, University College London, UK, June 28, 2023. Presentation to 100 scholars.
- Invited keynote Presentation (in person and hybrid mode): Mills, K.A. *Using Mixed Reality for 3D Multimodal Design*, Sheffield Hallam University, Sheffield, UK, June 22, 2023.
- Peer reviewed Conference Presentation, UKLA United Kingdom Literacy Association: Mills (in person), Scholes (lead author), Rowe and Gutierrez: *Utilising gaming texts for reading and writing in the classroom*, June 24, 2023. 500 delegates, well-attended presentation (full room).

National

- AATE/ALEA National Conference, Challenge & Change: Contemporary Literacy & English Teaching, Brisbane (2021, July 7–9). Keynote by Professor Mills: The Future of the Digital Turn in the New Literacy Studies.

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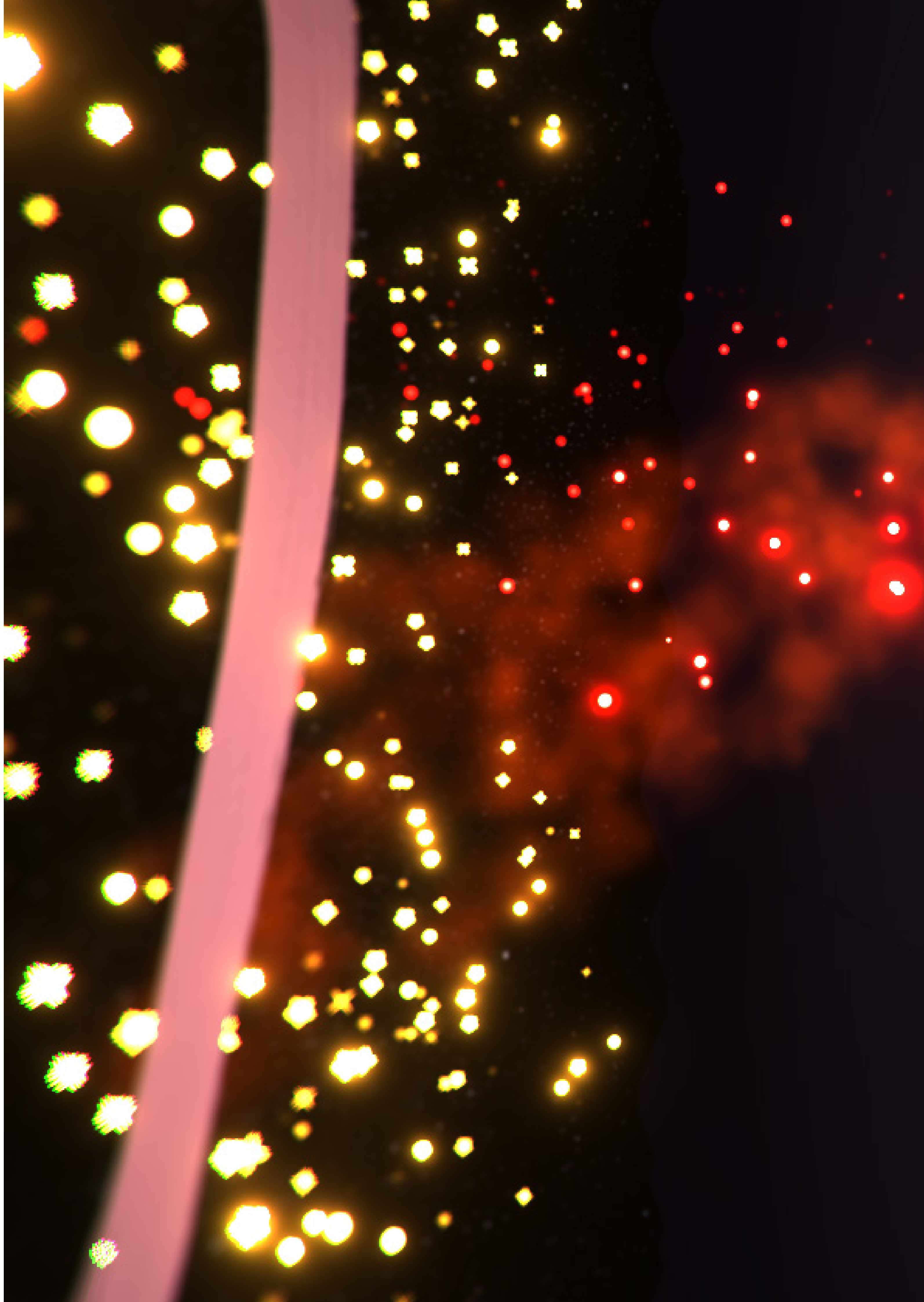

Glossary

Augmented Reality (AR) A technology which augments a user's perception of the physical, real-world environment. Virtual information, including graphics, written text, or audio, are overlaid on the real-world environment, appearing within the user's field of vision. AR can be experienced using a headset, smart glasses, or through devices like a smartphone, tablet, or smart display.

Embodiment The function of the body in situated cognition. Situated cognition is a theory that suggests that knowledge and learning are strongly influenced by the context or environment in which they occur.

Embodied cognition Thoughts and understanding are prompted by our body and how it interacts with the world. It suggests that our senses and movements play a vital role in how we think and process information.

Haptics Any device that can simulate the sensation of touch by exerting pressures, vibrations, or movements on the user is referred to as haptic technology, also known as kinaesthetic communication or 3D touch.

Locomotion Refers to the movement of the feet and legs when using a head-mounted display (HMD) wearable device.

Makerspace A makerspace is a place where people can come to create and work on projects together. Makerspaces are typically located in community orientated venues such as libraries, museums, and science centres. Makerspaces typically consist of a wood, clay and sculpture materials, 3D printing, audio-visual equipment, and hand tools.

Mixed Reality (MR) There is no single definition of "mixed reality," as the term is used in a variety of ways. Generally, mixed reality refers to the merging of real and virtual worlds to create a hybrid, interactive environment. This can be done using a variety of technologies, including augmented reality, and virtual reality.

Multimodality/Multimodal Multimodality is the use of multiple communication modes to convey a message. Modes of communication can include linguistic (written and spoken), visual (images, videos, and gestures), aural (sounds), and spatial (the use of space and proximity).

Pedagogy The method and practice of teaching, especially as an academic subject or theoretical concept (Oxford Dictionary, n.d.)

Semiotic Semiotics refers to the study of signs and symbols and their meaning in communication.

Sensoriality Sensoriality is the capacity to perceive and interpret sensory information received through our senses, such as touch, taste, smell, sight, and hearing. Sensoriality plays a crucial role in our daily lives as it enables us to gather information about the world around us, make sense of it, and respond appropriately.

Smart Glasses A display module incorporated inside the frame or lenses, sensors for detecting movement and orientation, a built-in or attached camera for taking pictures and movies, and wireless connection to communicate with other devices or access the internet are the usual components of smart glasses. For audio feedback, certain versions additionally come with speakers or headphones.

Transmedia Transmedia refers to a storytelling technique where a narrative or story is expanded across multiple media platforms or channels.

Transmediation Transmediation is complex because there is no pre-existing code or ready-made link for representing the interpretant of one sign system into another. Each sign system or mode has differing features that enable and constrain the way that ideas are conceptualised, symbolised, represented, and remembered (Forman, 1994).

Typology A systematic classification or categorization of objects, phenomena, or concepts based on their characteristics, properties, or features. It is a method of organizing information into distinct groups or categories to facilitate analysis, comparison, and understanding.

Virtual Reality (VR) Virtual reality technologies provide a synthetic or computer-simulated environment for user-immersion involving the use of a head-mounted display (HMD) for stereoscopic vision, and motion-tracking controls for haptic-feedback in the virtual environment (Velev & Zlateva, 2017).

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