Learning how to see: understanding binocular vision and the benefits for students of art

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Learning how to see:
understanding binocular vision and the benefits for students of art

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Abstract

What can students of art gain from learning about how their visual system works? What can the way we *see* teach us about the nature of experience or representation of space? By virtue of having two eyes, we are gifted the rich experience of three-dimensionality. Yet we are generally unaware of the complex process which makes this possible. This paper discusses activities held as part of an Interdisciplinary Art course at a liberal arts college in Japan in which students are encouraged to investigate firsthand the nature of their own visual experience. By recreating phenomena of binocular vision through a combination of drawing, 3D photography, and creating viewing devices, students can reflect on *seeing* in new and interesting ways. There are several benefits to such experimental modes of firsthand inquiry. Firstly, by encouraging visual art students to be more aware of how they interpret visual information (in essence, how they *see*) they can develop more refined methods of spatial representation, both in a physical and philosophical sense. Secondly, understanding how vision works could benefit students interested in working in creative industries involved with virtual reality (VR) technology, such as gaming and entertainment. Finally, this hands-on approach to theories of vision is accessible and exciting, helping foster an interest in contemporary critical art practice.

Keywords: 3D, stereopsis, representation of space in art

Introduction

Understanding and representing three-dimensional (3D) space is perhaps one of the most elusive skills for artists to master. Among the traditional elements of artistic representation (including line, shape, color, value, form, and texture), space offers a challenge unlike the others in its difficulty to define, rationalize, and represent in a consistent way. This challenge is evidenced by the array of spatial interpretations throughout art history: from the structured, tabulated representations of ancient Egypt, the illusionistic realism of Renaissance linear perspective, or the Cubist conceptual treatment of multiple viewpoints synthesized into one.

Artists have long experimented with various devices to better understand space. Instrumental in the development of linear perspective, Filippo Brunelleschi used a mirror and canvas with holes in them to sketch the Florence baptistry in perfect proportions. Albrecht Dürer invented a series of drawing machines which used string grids and fixed eye positions to create images with an incredibly natural sense of depth. Yet it was the relatively recent invention of the stereoscope in the 19th century that first enabled the reproduction of true 3D as is experienced with both eyes. This paper argues that there are several benefits to art students from learning about depth perception through the creation of, and experimentation with, stereoscopic devices. After outlining the fundamentals of how we use both eyes to see in 3D, this paper will discuss ways in which such activities could be used to deepen students' understanding of how they perceive the environment and how this physiological and philosophical knowledge might assist them in their creative practice. The case study of a 3D unit taught at a liberal arts university in Japan will be introduced to illustrate concrete examples of classroom activities. Finally, student feedback will be examined.

Seeing Space

Human depth perception relies on the combination of monocular and binocular information - using one eye or both eyes together. The first category is perhaps the more familiar, and includes occlusion (closer objects overlap those further away), linear perspective (parallel lines converge in the distance), relative size (closer objects appear larger), shadow and shading (3D shapes revealed by light), aerial perspective (distant objects appear hazy due to particles in the air), and relative motion (closer objects appear to move faster). In fact, with only one eye we can already experience a fairly rich 3D impression of the environment. However, it is by using both eyes together that we can create the "distinctive, subjective sensation" (Barry, 2009) of depth, and arguably the most convincing experience of 3D.

Stereopsis is a remarkable feature of human perception yet is often overlooked in our everyday lives. The horizontal separation between the left and right eye results in slightly mismatched images being projected onto each retina. Providing the images are close enough, the brain fuses them together to give us a convincing three-dimensional experience of the world. If the difference is too great, say we look at two very different objects at the same time (one in each eye), then one may be suppressed in a binocular rivalry (BR) experience. Despite our lack of awareness of these background processes, they are constantly at work and essential in creating the richest possible 3D experience.

Despite theories of how we see in 3D dating back to the ancient Greeks, it was not until the invention of the stereoscope (see Fig. 1) by Charles Wheatstone in the 19^{th} century that we began to truly understand the process. Developed out of vision research in the 1820s and 1830s, the device was quickly adopted as a form of popular entertainment, helping disseminate knowledge from academic theory to practical understanding. Wheatstone's use of mirrors and open-top installations in his 1838 invention helped elucidate the complex mechanism of 3D vision by making *seeing* itself the subject of observation.

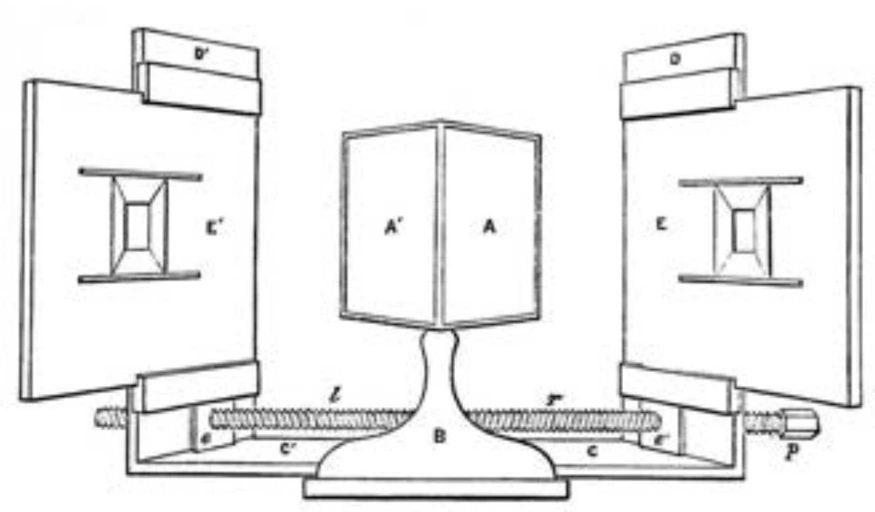


Figure 1: Wheatstone Stereoscope, 1838. Stereograms positioned at E are viewed via mirrors at A. This structure enables different images to be comfortably viewed simultaneously by each eye. Providing the images are similar enough, the brain will automatically fuse them together and create a unified experience of a single (3D) image.

Showing Space

The physiology of vision has defined the way in which artists represent space. Two-dimensional images projected onto our eyes send signals to the brain, which miraculously constructs a rich three-dimensional experience of the environment. The challenge of the artist is to reconstruct this internal experience in an (often) 2D representation.

Even though the most robust method of *perceiving* space is through stereopsis, it is interesting that *representations* of space almost exclusively rely on monocular depth perception. The use of occlusion to represent depth can be found in prehistoric paintings found in the Lascaux (c. 17,000 BCE) and Chauvet (c. 30,000 BCE) cave complexes as well as several ancient Egyptian artworks such as the Narmer Palette (c. 3100 BCE). Shadow and shading have an equally long history in art, with considerable use in ancient Greek painting and often combined with aerial perspective to create a convincing impression of space and depth.

The development of linear perspective in 15th century Renaissance Italy changed the rules of realistic representation forever, transforming the canvas from a flat plane to a “window through which we see the visible world” (Gombrich, 2014).

Looking at art through the ages, it is apparent that there are various techniques artists use to show depth. Yet, apart from disputed claims that Leonardo’s Mona Lisa was created as a pair of stereoscopic images (Brooks, 2017), 3D examples are noted for their absence from art history. Binocular depth perception seems to be mostly confined to the realms of entertainment: 3D photography, film, and virtual reality. There are practical reasons for this. Viewing devices such as stereoscopes or 3D glasses are generally required to experience 3D media. The impracticality of such apparatus, and loss of immediacy of experience when appreciating the art, is perhaps mainly responsible for the lack of stereoscopic artworks. This paper, however, argues that despite the lack of stereoscopic artworks, we should not underestimate the importance of understanding stereopsis itself in the artistic learning process.

Benefits of Understanding Binocular Vision

As discussed, there are many techniques that artists use to give the illusion of depth that do not require binocular vision. However, gaining a deeper understanding of how we interpret depth using binocular vision can help art students in several ways.

Firstly, an understanding of the physiology of our visual system can give us a deeper understanding of space itself, and ultimately ways in which this can be effectively represented. It might be argued that the techniques previously mentioned for showing depth (occlusion, shadow and shading, aerial perspective, and linear perspective) developed out of studying the senses. After all, our internal model of the spatial environment depends upon two things: the environment itself, and the way in which our senses internalize this visual information.

Historically, the arts and sciences were much less specialized than they are today with Da Vinci and Dürer being two often cited examples of interdisciplinarians. Perhaps through activities which transcend disciplines, such as those listed in this paper, a curiosity to learn more about our visual system can be fostered in our students.

Students are encouraged to question the relationship between object and image through stereoscopic experiments. Stereograms are flat images until seen through a stereoscope. The miraculous 3D experience exists nowhere but in our mind. In turn, we discover that what we *see* is not the same as what we *perceive*. Crary (1992) comments that devices such as the stereoscope "made unequivocally clear" the "fabricated and hallucinatory nature" of the image and created a "rupture between perception and its object". This kind of critical inquiry as it relates to vision and visuality is an important skill for students to learn and apply to their creative practice.

VR technology is becoming ever-more widespread in the expanding gaming and entertainment industries. Opportunities for employment in these areas for university graduates are also increasing. In addition to core artistic skills, an understanding of 3D vision, on which the VR experience depends, will be a great asset to art graduates aiming to pursue a career in related fields. Firsthand experimentation with 3D devices can provide students with this understanding.

Finally, through the following activities, students are encouraged to make connections between art and other disciplines. Interdisciplinary learning that intersects perceptual psychology, healthcare, philosophy, and art, can lead to new discoveries and original thought.

The Activities

Background

The following activities were held in the Fall semester in the Interdisciplinary Art course at an undergraduate liberal arts college in Japan. The course explores art that transcends traditional boundaries and challenges the perceived division between disciplines such as psychology, brain science, and medical care. Through theoretical and practical study, students are encouraged to apply what they have learned in various practical investigations. The following activities are part of the eight-class unit: "From 3D to 2D (and back again)" in which students learn about how we see and represent depth in a physiological, philosophical, and artistic sense. The unit encourages students to consider 3D space in new and interesting ways. We do this by learning about representations of depth in an art historical framework while at the same time discovering first-hand how we create an internal 3D representation of the environment. The hope is that students can make new connections which will inform exciting directions in their creative practice. Twenty-one students took part in the following activities in the Fall semester of the 2020 academic year.

Method

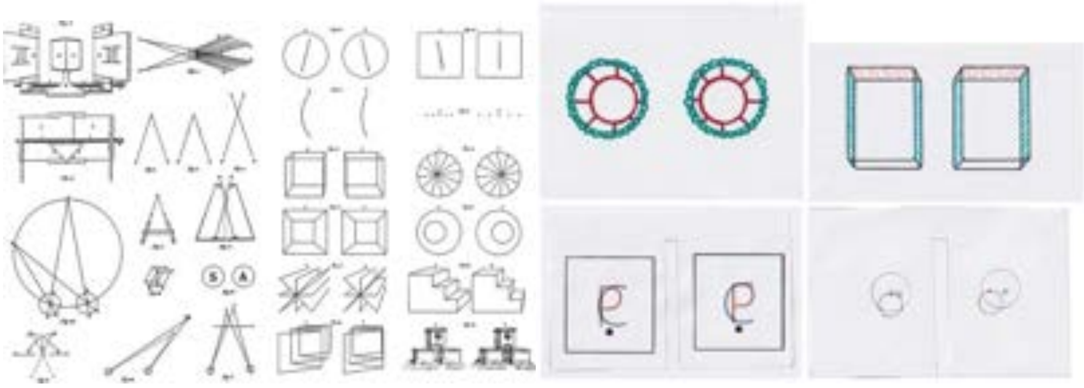
First, an outline of historical methods of depth representation in art is outlined, with a focus on transformational developments such as linear perspective in the Renaissance period (Masaccio, Brunelleschi, Durer, etc.). Next, the groundbreaking 3D vision research of Charles Wheatstone is investigated, learning about how the visual system works on a physiological level, and the various devices Wheatstone invented to test his ideas. Students are then introduced to several stereoscope designs and can experiment firsthand with creating and experiencing stereograms (see Fig. 2).

Figure 2: various stereoscopic device designs used by students to experience simulated stereoscopic depth perception. Despite the differences in the various designs, the physiological principle remains the same: two slightly different images, shown simultaneously to the left and right eye, are fused by the brain to create a 3D experience.

Due to limited time, students were not able to create their own stereoscopes. Making the devices themselves is time consuming and would need to be done over several classes. However, this is a consideration for future development in the Interdisciplinary Art course. The following stages describe students' experiments with the stereoscopes.

Stage 1: making original stereograms

Stereograms are the 2D images which are fused together by use of a stereoscope to create a 3D experience. Stereograms can be drawings, photographs, or digitally produced images. The important point is that the two images illustrate the views seen by the left and right eye. The images are similar enough that when seen side-by-side without the use of a stereoscope they may appear to be identical. However, closer inspection will reveal subtle differences and when they are fused together the distinctive, subjective sensation of 3D depth becomes apparent. Wheatstone's invention of the stereoscope came just before that of the camera. For this reason, the first recorded stereograms were in the form of drawings rather than photographs. Taking these simple, but elegant, line drawings (Fig. 3) as inspiration, students began to experiment by creating their own versions, eagerly cutting them out to view them through the stereoscopes and see if they work (Fig. 4).



A B

Figure 3: Charles Wheatstone's original stereogram drawings (A) used to demonstrate 3D vision by stereopsis (Plate 2 from Wheatstone 1838) and Wheatstone inspired original drawings by students (B). The left and right images are fused by viewing through a stereoscope to produce a 3D experience.

Figure 4: stereograms being viewed with a stereoscope.

Stage 2: experimenting with binocular rivalry

Through these initial trials and experiments, several students noticed something very interesting. By showing significantly different images simultaneously to the left and right eye, they found that they were unable to fuse them together. Under such circumstances, we might expect that we would perceive a mixture of the two images, one overlayed on the other. However, the result is more surprising. They noticed that they would *see* one image for a moment, then it would disappear, and the other image would come into their mind. The students noticed that these strange *flips* in their mind's eye would continue for as long as they looked at the images. They had discovered the phenomenon of binocular rivalry (BR). If the images in each eye are too different to be fused, then the brain struggles to create a coherent impression and we experience perceptual switches back and forth between the two, with one temporarily dominating our perception and the other being suppressed in an unusual bistable perceptual experience (Alais & Blake, 2005) (Fig. 5).

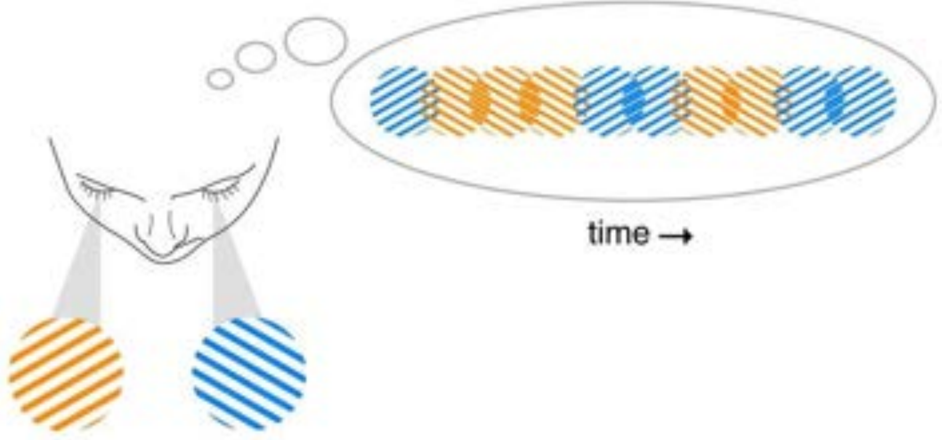


Figure 5: The phenomenon of binocular rivalry (BR). Viewed simultaneously with left and right eye, the different images will switch back and forth, temporarily dominating conscious perception.

Students experimented with hand drawn and digitally created collaged BR images. Starting off with similar left and right eye images, then gradually making them increasingly different, testing the limits to which they could push the brain's power of visual synthesis. Up to a certain point the brain can combine slightly different images together to create a single impression. However, as students discovered, if the two images pass a certain degree of dissimilarity, then the system collapses, and we experience the perceptual flips of BR. Most interesting was some student's use of different language texts: English in one eye, Japanese in the other, with a common element like a circle or square to unify the images (see Fig. 6).

Questions surrounding what happens to the suppressed image, and whether this perceptual switch can be controlled, are of great interest to vision, brain, and philosophy of mind researchers, and have led to BR being touted as an important tool in the ongoing search for the "neural correlate of consciousness" (Crick and Koch, 1998). The appeal of using BR for consciousness research is that information projected on our eyes can effectively be detached from our conscious experience (Wolfe, Kluender, & Levi, 2020). In this respect, there is a clear relationship between BR research and the "philosophic toys" (Wade, 2004) of 19th century vision research, such as the Wheatstone stereoscope. This borderland between the conscious and subconscious mind, effectively the gates of perception, has been the topic of exploration by the author both in foreign language acquisition (Hall, 2020) and interactive artwork aiming to produce emotional responses (Hall, 2013).

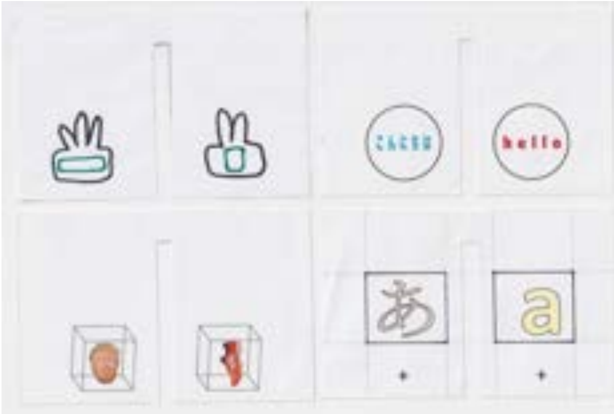


Figure 6: Student experiments with the unusual perceptual experience of binocular rivalry (BR). Different images shown simultaneously to each eye create a bistable image in the mind which switches uncontrollably between the two.

Stage 3: anaglyph 3D photography

Students now had a solid understanding of the mechanism behind 3D. The next step was to experiment with 3D photography. The purpose of demonstrating stereopsis using mirrored or lens-based stereoscopes was to make the principles of 3D vision explicitly clear. Students can easily understand that the left and right eye see a different image, which the brain then fuses to create 3D. In truth, however, the experience can be simulated by several different methods. One of the most accessible and inexpensive of these is the familiar red and blue anaglyph glasses. Until quite recently, the glasses were the most common way of viewing 3D films and are also suitable for demonstrating 3D photography with students.

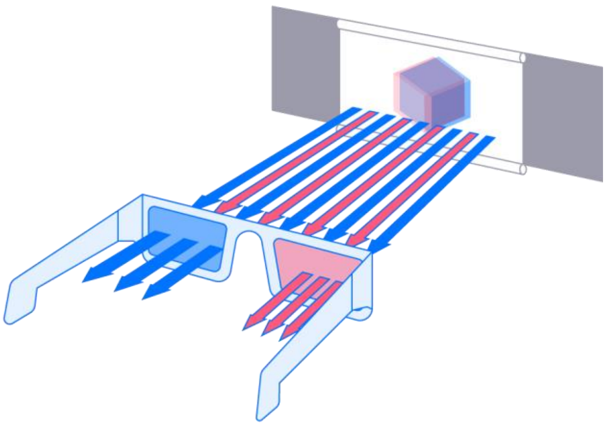


Figure 7: inexpensive anaglyph glasses can be used to demonstrate 3D photography

In normal 3D photography or film, two cameras positioned next to each other record an image simultaneously. The images capture the same scene from slightly different perspectives, mimicking the views seen from each eye. Similar still images can be created using a single camera, simply by taking one photograph, moving the camera 6cm horizontally, then taking another. This method was discussed with students, they were then set the task of creating several stereogram pairs. After the pairs of images had been created, they were edited and combined to produce a single 3D photograph. This was done using Photoshop by isolating the red, green and blue (RGB) color channels in each image. The R color channel was removed from one image, and the G and B color channel removed from the other. The images were then overlayed on top of each other. In this way, when viewed with the anaglyph glasses, each eye is shown a different image.

Students seemed excited to tackle the new challenges of working with 3D photography. While they were already accustomed to the methods and techniques involved in creating visually interesting 2D photographs, they now had to consider an additional dimension, bringing to bear a sculptural quality to a format previously thought of as essentially flat.

Figure 8: Anaglyph photographs created by students. When viewed using anaglyph glasses, the images are experienced in 3D. With the additional third dimension, students needed to consider the sculptural quality of their photographs.

Stage 4: virtual reality (VR) experience

One of the most exciting uses of 3D imagery today is the ever-expanding area of VR. The possibilities of VR are vast; from its use in entertainment, education, health care, and the military, there is great potential for VR to disrupt traditional activities. The uniquely immersive nature of VR is so convincing that it needs to be experienced to be truly appreciated. Once experienced however, the limitless possibility becomes apparent.

Most students were familiar with the concept of VR, although few had experienced it firsthand. The VR experience was intentionally held at the end of the unit, after students had gained a deep understanding of how 3D experiences are created. With this knowledge, they could approach the technology with the eyes of a researcher, curious to begin a new experiment, rather than a consumer of entertainment. VR headsets are designed to hide the mechanism behind the experience as much as possible, focusing the user's attention on the experience itself. Coming with the knowledge gained from the previous activities, students were able to see through the "black box" and confront the experience with the informed curiosity of a scientist.

Figure 9*:* the VR experience came at the end of the unit and drew on knowledge gained throughout previous activities.

Student Feedback

A student survey was conducted at the end of the 3D unit. Due to some absences, 17 out of 21 student responses were recorded. According to student responses, their understanding of 3D vision greatly improved during the unit. Before studying the unit, most students (82.3%) had "limited" or "no understanding of how we see in 3D". After finishing the unit, all students reported having at least "some understanding", and 76.5% reported they have "a deep understanding of how we see in 3D" (Fig. 10).

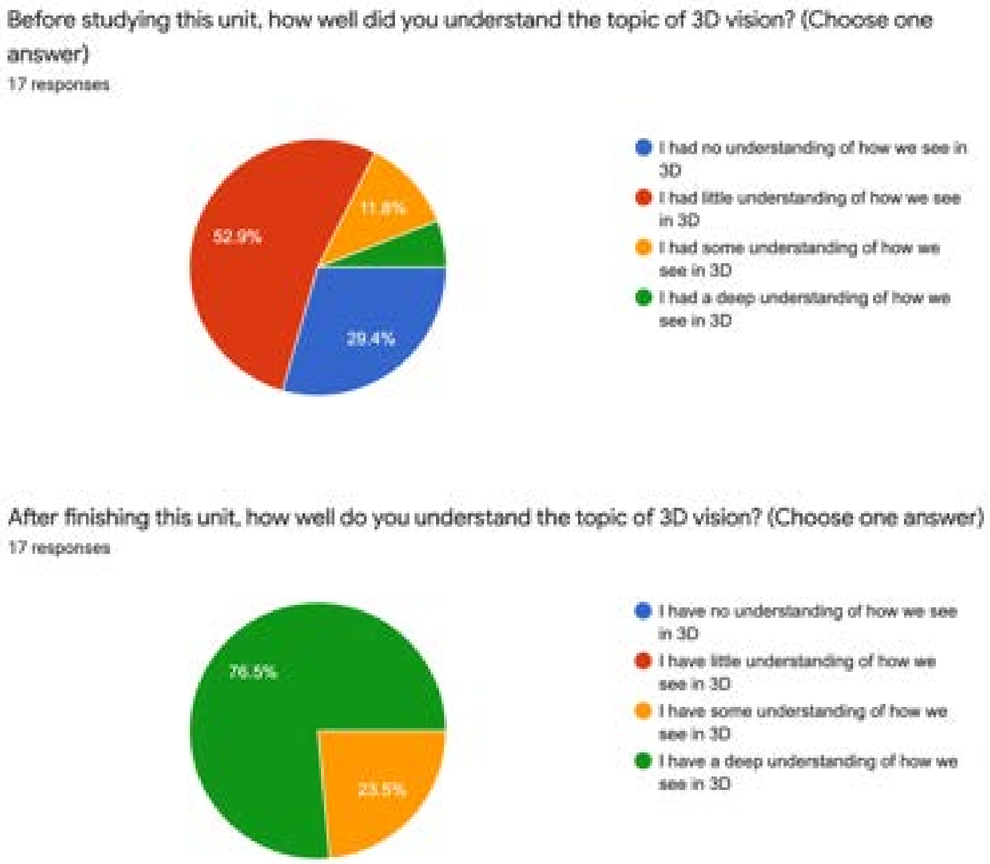


Figure 10: student understanding of 3D vision greatly improved during the unit.

It was eye-opening to see students' responses when asked what they found interesting about the unit. Despite the unit being part of a visual art course, comparatively few students were interested in learning about artistic techniques to show 3D space (35%), while learning about how the visual system works, a topic normally reserved for science classes, was apparently more interesting (64.7%). Perhaps unsurprisingly, the most interesting aspect was experiencing VR (76.5%). While it is hoped that this positive response was helped by the order in which the activity came (at the end of the unit; drawing on knowledge gained about 3D vision), further research is needed to prove this.

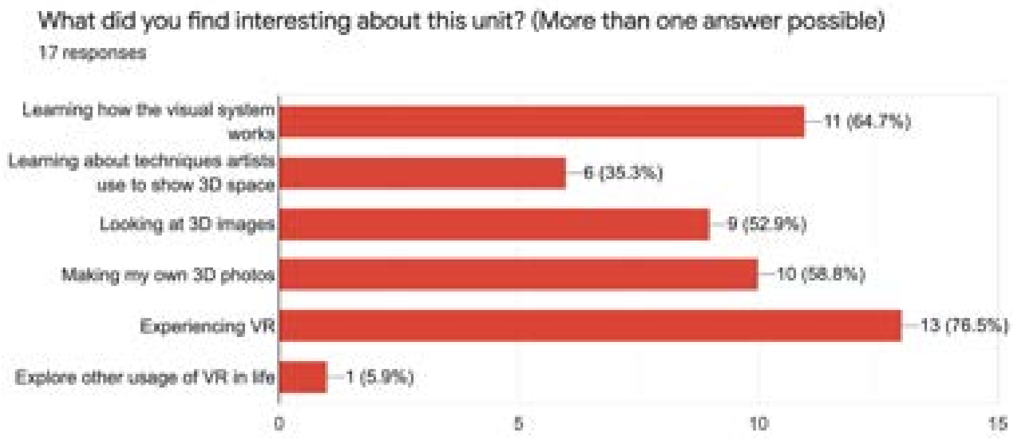


Figure 11: student responses when asked about their interest in the activities was surprising.

Student responses to the open question "what was most interesting about this unit?" seemed to support the notion that a combination of theoretical and practical activities is most engaging. One student answered: "*As I personally like to learn theories best, I enjoyed learning the theories and principles of how we perceive things in 3-D and how artists produce 3-D effects in their artworks*", while another responded "*It looked 3D and the experience of using VR was interesting. But what was most interesting was that I was able to understand its structure.*"

Conclusion

Representations of spatial depth in art have varied throughout history and across cultures. While there have certainly been important developments, such as linear perspective, the lack of any persistent method or rules suggests that notions of spatial representation are complex, and perhaps reflections of contemporary thought and technological developments. The understanding of stereopsis in the 19th century was a landmark discovery in our understanding of how we see depth. This paper argued that there are several benefits to art students from learning about the principles of stereoscopic vision through firsthand experiments, including: a deeper understanding of our spatial environment and how we might represent it, a critical awareness of the relationship between object and image, and increased opportunities for pursuing a career in creative industries which rely on 3D technology.

The activities outlined in the second half of the paper suggest ways in which these concepts might be explored by students in creative and engaging ways. While the possibility of introducing activities such as these depends on many factors, such as available resources, time, and student motivation, most could easily be adapted to be suitable for a range of educational environments.

Figures

All images were made by the author or students. Except:

Figure 1: [PSM V21 D049 Wheatstone stereoscope 1.jpg] (2010). Retrieved from https://commons.wikimedia.org/wiki/File:PSM_V21_D049_Wheatstone_stereoscope_1.jpg#filelinks

Figure 3 (A): Wheatstone C., 1838 `Contributions to the physiology of vision - Part the first. On some remarkable, and hitherto unobserved, phenomena of binocular vision" Philosophical Transactions of the Royal Society of London 128 371-394

Figure 7: Retrieved from https://courses.vrtl.academy/lessons/whats-up-with-stereoscopic-and-virtual-reality/

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