

## Engaging Pre-Service Mathematics Teachers in Creating Spatially-Based Problems in a 3D Virtual Environment: A CAVE2™ Experience

Margaret Marshman

*University of the Sunshine Coast*  
<mmarshma@usc.edu.au>

Geoff Woolcott

*Southern Cross University*  
<geoff.woolcott@scu.edu.au>

Shelley Dole

*University of the Sunshine Coast*  
<sdole@usc.edu.au>

The use of multiuser virtual environments for educational purposes is in its infancy but offers potential for exploration of spatial contexts that could not otherwise be experienced. We report on pre-service teachers' experiences in designing learning activities as a result of immersion in the CAVE2™, a 320-degree, cylindrical 3D virtual environment. Observation of student actions and analysis of student-developed artefacts indicated that 3D and 2D interference impacted the design of immersive learning experiences. We hypothesise that pre-service teachers' capacity to recognise and seize the potential of the CAVE2™ for promoting spatial reasoning is predicated on their own spatial reasoning capabilities.

The use of spatial reasoning (or spatial thinking) is integral to human lived experience via spatial interaction in a three-dimensional (3D) world. Spatial thinking can be considered simply as using spatial memories from life experiences. This can vary from simple tasks like visualising windows in a room, walking along a known path, or estimating size, quantity, or distance of objects, to more complicated tasks, like rotating an object in the mind, drawing a two-dimensional (2D) image of a 3D object, or using a mirror to reverse a car. Spatial reasoning embraces natural abilities, such as navigating the environment and recognising objects or identifying and utilising spatial patterns and their structural relationships that are fundamental to both mathematical and non-mathematical conceptual development (Mulligan, English, Mitchelmore, & Crevensten, 2013). Being able to think spatially is important for our everyday problem solving, and equips school students for success, not only in mathematics, but in science, technology, engineering, and mathematics (STEM) and other subjects (Wai, Lubinski, & Benbow, 2009). The ability to move between 2D and 3D visual environments is a critical part of spatial reasoning skills and competencies (Bruce et al., 2016; Uttal et al., 2002). These skills are important in the real world, such as in interpreting architectural plans and map making/reading.

Located at the University of the Sunshine Coast is a unique learning environment known as the CAVE2™. This is an immersive environment that enables 320-degree panoramic views of virtual objects and displays. As its name suggests, you step into the cave and are immediately immersed in whatever environment is projected on the walls. You can view projected 3D objects that appear to "hang" in space from whatever angle that is rotated. The virtual space is controlled by one person who sends commands to the screens to provide the immersive experience. The CAVE™ comfortably accommodates groups of approximately 15 people. The carpeted floor invites sitting or lying to maximise the experience if desired. As a new learning space with potential to develop spatial reasoning and thinking, pre-service teachers were provided with a CAVE2™ experience and tasked with developing learning activities suitable for primary school students. As part

of a larger study investigating multiuser virtual environments and associated technologies, this paper is a report on a scholarly inquiry in progress.

## Significance and Background

Spatial reasoning is an important life skill and it is a recognised component of the Australian Curriculum: Mathematics (Australian Curriculum, Assessment and Reporting Authority, 2016). Yet many people, both teachers and students, find spatial reasoning difficult (e.g., Marchis, 2012). Recent review publications on implementation of the Australian Curriculum have indicated a shift in curriculum foci to strands concerned with spatial reasoning, such as Measurement and Geometry (Atweh, Goos, Jorgensen, & Siemon, 2012). However, it has also been reported that school curricula have only recently begun to recognise the value of teaching that encompasses spatiality (Bruce et al., 2016). Published reports provide blueprints for incorporating spatial reasoning into the curriculum, including a focus on early years education (Davis et al., 2015), and in secondary and tertiary education (Wai et al., 2009). Specific studies have attempted to isolate spatial elements such as spatial visualisation, sense, and orientation (Bruce et al., 2016), whilst others have looked at classroom or other learning environments in a more general or systemic sense (Francis et al., in press). Spatialisation of the curriculum underpins a new vision of how mathematical concepts are formed and connected and how they develop from interaction with the 3D world in both a mathematical way and a non-mathematical way (Davis, 2015).

Defining spatial reasoning is challenging. Definitions incorporate notions of locating, orienting, decomposing and recomposing, navigating, patterning, scaling, transforming, and seeing symmetry. In this paper, we use the definition of the Spatial Reasoning Research Group (of which Woolcott is a member), an international collaboration dedicated to investigating spatial reasoning in educational contexts. Spatial reasoning (or spatial ability, spatial intelligence, or spatiality) is “the ability to recognize and (mentally) manipulate the spatial properties of objects and the spatial relations among objects” (Bruce et al., 2016, p. 2).

Spatial reasoning has a significant role in twenty-first century education (Hegarty, 2014), particularly given its strong correlation to mathematics achievement (Uttal et al., 2013). “There is over a century of research showing strong correlations between spatial reasoning and mathematics performance... and yet we know very little about what this means for educational application.” (Bruce et al., 2016, p. 15). Lowrie, Logan, and Scriven (2012) argued that spatial reasoning needs to be connected with a diversity of mathematics learning environments. Spatial reasoning helps us make sense of the 3D world of objects and space by mentally inserting ourselves into a spatial situation to solve a problem, contextualising the spatial elements. Recent investigations of the use of spatial reasoning in the Australian Curriculum: Mathematics (Measurement and Geometry) by Lowrie and colleagues (e.g., Lowrie, Diezmann, & Logan, 2012; Lowrie & Jorgensen, 2015; Lowrie, Logan, & Scriven, 2012) have suggested that there is considerable potential for application of rich visual or spatial tasks. Despite the potential impact of spatial reasoning on mathematics education, the associated skills and competencies may not always exist in either classrooms or in the teachers operating in those classrooms, in some part due to a focus on number or arithmetic (Mulligan & Woolcott, 2015). In classroom settings, students may be required to draw a 3D object in 2D, make a 3D object from a 2D plan, or to connect a 2D net with a simple 3D object, both with and without the use of digital

technologies. These skills and competencies can be improved in both children and adults (Newcombe, 2013; Uttal et al., 2013).

Spatial reasoning experiences have the potential to improve mathematics learning as they enable access to complex mathematical ideas in non-traditional ways. Virtual environments and new technologies are relatively untapped and under-researched resources for developing spatial reasoning. Dalgarno and Lee (2010) report that virtual environments support increased knowledge of spatial representation, opportunities for contextualised and experiential learning, as well as increased motivation, and collaboration compared with 2D activities. Barrett, Stull, Hsu, and Hegarty (2015) report that being provided with experiences where you feel that you are moving, assist with learning the layout of an environment when in a virtual environment. Gregory et al. (2015) have reported on the range of virtual environments available for education. Kennedy-Clark (2011) has reported on pre-service teachers operating in these kinds of environments for science education. Camilleri, de Freitas, Montebello, and McDonagh-Smith (2013) have reported on the engagement value of such experiences compared to that of a traditional classroom or other online experiences. There are no current studies that have explored the impact of a CAVE2™ experience on pre-service teachers' own spatial reasoning and their capacity to use this environment to solve spatial reasoning tasks and create activities.

The focus in this study was in providing learning experiences for pre-service teachers that centred on spatial reasoning, and includes examination of both learning (as understandings) and perceptions. The aim was to develop in the pre-service teachers an awareness of their own spatial reasoning skills and competencies so that they were then aware of their strengths and weaknesses when helping their future students develop spatial reasoning skills in the classroom. We consider the following research questions:

1. How does immersion in a virtual 3D environment impact pre-service teachers' spatial reasoning competence?
2. What is the capacity of pre-service teachers to utilise this virtual environment to design and solve rich spatial reasoning tasks and activities?

## The Study

In this study, three groups of pre-service primary teachers (group size approximately 25) were scheduled to undertake their normal two-hour course tutorial in the CAVE2™. Prior to this tutorial, the focus of the course lecture material was on the importance of developing children's spatial reasoning and the role of this within the mathematics curriculum. The CAVE2™ is located within a purpose-built learning space that includes open space outside the actual cave where desks and computers are located. This enables in-cave and out-of-cave learning to flow. The pre-service teachers were guided through tutorial material associated with spatial reasoning, with the cave experience integral to the planned tutorial for that week.

The selected cave experience was a flyover video of the region surrounding the campus, guided by the manager of the Visualisation Facilities. This immersive experience simulated a helicopter or airplane ride of the real local environment within a 65 km radius from the campus site. This flight took in local coastline and mountain terrain. Prior to the immersive experience, the pre-service teachers were asked to think about how this experience could develop spatial reasoning in primary school children. After the experience, they were required to work in groups to develop a mathematical question or problem that they could solve using the CAVE2™ experience. Throughout the tutorial, the participants could move freely in and out of the visualisation space, and also ask the

operator to take them to the part(s) of the video that they wished to see again so that they could collect data that they wanted to use to solve or think about their problem.

Data collected and reported here were analysed thematically and came from the following sources:

- Field notes kept by the first author who attended each session
- Participants' questions and some solutions (not all provided their solutions)
- Participants' responses to reflection questions shown in Figure 1

When you were using the CAVE:  
*How did you identify your problem(s)? What stimulus did you use?*  
*How did you solve your problem(s)? What knowledge or resources did you find useful?*

When you were using the map:  
*How did you identify your problem(s)? What stimulus did you use?*  
*How did you solve your problem(s)? What knowledge or resources did you find useful?*

*Figure 1.* The reflection questions given to the pre-service teachers.

## Results and Discussion

### *The CAVE2™ Experience*

The immersive experience appeared to engage all pre-service teachers. They were very keen to step into the cave where they were surrounded by a virtual image of their immediate local environment (i.e., the grassy area outside the building). Students rotated themselves to take in the panoramic view presented to them. They expressed surprise of the realistic nature and that they felt that they were actually standing outside. The cave operator then commenced the “flight” over the buildings and provided students with an aerial view over the university campus. Students identified buildings and other familiar landmarks. For some students, the movement was disconcerting and they experienced some sensations of nausea. They only needed to look down at the floor for a few minutes until this feeling dissipated. No students refused outright to continue with the cave experience due to these sensations. The operator extended the “flight” to take in the local coastline. Students picked out local landmarks and also tried to locate their own houses.

What was noticed by the researcher and tutors was confusion experienced by pre-service teachers due to shapes changing depending on the angle from which they were viewed. For example, at this university, there are straight paths joining buildings on either side of a large lawn. Initially, standing in the CAVE2™ environment, there appeared to be two separate paths as in Figure 2. As the pre-service teachers “walked” through the environment, the paths moved together and joined into a straight path in the centre of the room and then bent the other way if you continued across the room. This generated considerable discussion about whether the CAVE2™ environment is realistic and how it distorts the senses of how the environment should look. There appeared to be general consensus that this would be too confusing for primary school children.

Another example of the CAVE2™ environment impacting students' spatial understanding related to parallel lines. In the lecture prior to the cave experience, the definition of parallel lines had been presented to students with the usual definition as “lines that never meet”. At this particular university, its main entrance is via a semicircular road, each side of which then continues as parallel roads ending in carparks. The “flight” over

the university enabled students to look at these roads and, due to perspective, the roads appeared to move towards each other. This led to quite a heated discussion with one group, as two students were certain that the roads were parallel from their personal experience, but they stated that they could not be parallel as they appeared to meet in the distance. This caused considerable confusion for students M and D. Student M could not resolve it during the session, even though the tutor discussed other roads, such as long straight country roads that appear to disappear to a point on the horizon. This was extended to discussion about the experience of driving on roads and the fact that the width of the road does not (overly) change so the edges of the road are effectively two parallel lines. At this stage, Student M was unable to reconcile the mathematical definition of parallel lines, as “lines that never meet” with personal experiences in the “real world”. To Student M, geometry belonged in a textbook, and she had difficulty changing that view. There was also concern about possible confusion with children in their future classes: “Parallel lines may meet with perspective will then confuse children like M and D confusing their definitions of parallel.” (Reflection by one of the pre-service teachers involved in the heated discussion.)



*Figure 2.* The image of the path between the two buildings from the door.

For the majority of pre-service teachers, the “flight” enabled them to make sense of their suburb and to make the suburb “fit together” with respect to where particular places were located. Whilst viewing the flyover, one said “Wow, I live there” pointing to the screen, “and the creek is just over there! It is not very far away at all. When you drive there or walk there, you have to go all the way around there, which is quite a long way, but it is just there! I had no idea, even when I looked at the map.”

### *Problem Solving in the CAVE2<sup>TM</sup>*

For the design and solution of a spatial reasoning activity using the CAVE2<sup>TM</sup> as a resource, the pre-service teachers typically chose to work collaboratively. They submitted just one set of results for their group and very similar reflections of their conversations. Selected examples to highlight key findings about pre-service teachers’ capacity to embrace the immersive environment for teaching and learning purposes are presented here.

*Example 1.* The CAVE2<sup>TM</sup> experience led to many students wondering about their local region. One student wrote:

- Sustainability – How has the environment changed, how much has been developed → population growth, reduction in farming?
- How much income was lost as a result?
- What are the new industries/ forms of income?
- How much ‘free space’ is left in the Sunshine Coast area?
- How many more people can move into the Sunshine Coast area?

In this case, the CAVE2<sup>TM</sup> provided an opportunity for experiential learning (Delgarno & Lee, 2010) by immersing the pre-service teachers into the local environment and enabling them to imagine how their local area has changed over time. These were rich mathematical questions with real-world and cross-curricular links. The pre-service teachers demonstrated spatial reasoning skills and competence in moving between 2D and 3D (Bruce et al., 2016; Uttal et al., 2002) when they identified that solving these problems included mapping over timelines and considering geographical landmarks. However, there was little in-depth thinking of these questions and reflection upon the CAVE2<sup>TM</sup> resource. The CAVE2<sup>TM</sup> was not going to be useful to solve the problems as identified as they would need to go elsewhere to find the solution using estimation from mapping data.

*Example 2.* Many pre-service teachers were not confident or competent in their spatial thinking and found it difficult to relate to 3D problem solving. So, they changed the problem into a more familiar traditional “school-type” 2D problem that they could solve. For example, questions included: “When the perspective of the area shifted facing west and gave a view of the coastline, it activated my wonder of the features of the Sunshine Coast. How high were we flying?” However, the pre-service teachers did not feel competent in solving the 3D problem, writing comments such as: “Having the question from the 3D experience in mind with no way of solving at present time I thought I would solve a similar question relative to the 2D visual”. These pre-service teachers solved 2D problems such as: “What is the length of the Obi Obi River from the Kondalilla National Park to the Baroon Pocket Dam?”, “How far is it from Narrows to the bakery at Montville?”, and “How long will it take me to walk the Great Walk from Kondalilla to Baroon Pocket Dam?”

*Example 3.* More concerning was the pre-service teacher who admitted in discussions with the researcher that she actually only thought about directions in 2D and that this was probably not a good way to teach it. Admitting her spatial skills were poor led to lots of discussion, and her group decided their problem was, “How could the CAVE be used to educate primary education students?” Acknowledging referring to themselves as the problem, they were keen for suggestions on how to improve their skills.

*Example 4.* Another group of pre-service teachers, in which three of the four had been in the army, found the experience confronting and had lots of discussion both inside and outside the CAVE2<sup>TM</sup> trying to resolve their thinking. They did not believe that it was possible or appropriate to be solving these types of 3D problems. One described the problem:

Without a scale, I decided a problem would not be authentic

In conjunction with a 2D map, it may work.

With a 2D map, scale can be worked out. It seems like an expensive YouTube video.

Engagement is a large factor; however, the problem of scale still plays a factor.

Prior experiences with map reading meant that this pre-service teacher was unable to see past these experiences. Perhaps he was reflecting back on “life or death” experiences where 2D maps had to be carefully studied and memorised prior to entering an area. As a whole, during this tutorial, this group spent considerable time in the CAVE2<sup>TM</sup> talking to the operator as he suggested ways that perhaps they could develop a scale. For example, at one stage, he showed them particular landmarks and asked them what size they were and how they could use the size of these landmarks to develop an approximate scale. However, they had argued that it wasn’t accurate and that it wasn’t a real scale. They were reluctant to consider estimation as part of their mathematics problem-solving toolkit. This near-refusal to problem-solve in this space led the researcher to reflect in her field notes: “I

don't think they believed that primary school mathematics, or any mathematics, belonged in the 3D world, or perhaps it was more of a concern with using estimation". For them, the problem needed to be situated and solved in 2D by: "us[ing] Google maps or 2D map".

## Implications and Conclusion

Pre-service teachers were provided with the opportunity to visit the CAVE2™, a 3D immersive visualisation facility, with the task of developing learning activities suitable for primary school students. While the 3D spatial environment was initially confronting, pre-service teachers generally found ways to utilise this unique resource and think about their personal spatial reasoning competence. For some pre-service teachers, there was confusion around shapes changing depending on the angle from which they were viewed and confusion around their spatial understanding related to parallel lines and perspective. The experience allowed many to make sense of their suburb as they viewed it from above.

Some pre-service teachers were able to demonstrate spatial reasoning competence and design questions that would lead to rich activities with spatial reasoning components, such as: "How has the environment changed, how much has been developed → population growth, reduction in farming?" There were others who were unable to solve their 3D questions and so solved 2D questions such as "What is the length of the Obi Obi River from the Kondalilla National Park to the Baroon Pocket Dam?" There were some pre-service teachers who could not utilise this virtual environment to design or solve rich spatial reasoning tasks and activities either because of their self-identified lack of 3D spatial reasoning skills or because they believed that "Without a scale, I decided a problem would not be authentic".

If pre-service teachers do not have spatial thinking and reasoning skills, they will not be able to help their students develop these skills. Both children and adults can improve spatial thinking with appropriate teaching and technology (Newcombe, 2013; Utall et al., 2013). Therefore, it is important that pre-service teachers are given opportunities to improve their spatial thinking and reasoning skills as part of their university education and are encouraged to continue developing these skills. The CAVE2™ provides a unique way for pre-service teachers to engage with and reflect on their 3D thinking and reasoning abilities and may provide the stimulus to seek to improve their skills. We are continuing to explore whether other resources in the CAVE2™ can be used to develop pre-service teachers' spatial thinking and reasoning. Interestingly, the CAVE2™ fly-over experience in this study resulted in a number of people experiencing motion sickness. This means that the experience has potential to support large-scale spatial learning in the same way as the real experience (Barrett et al., 2015).

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