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Using immersive and modelling environments to build scientific capacity in primary preservice teacher education

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Using Immersive and Modelling Environments to Build Scientific Capacity in Primary Preservice Teacher Education

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Abstract

Research has shown that primary school teachers often have a poor background in science and scientific concepts, and as a consequence may feel particularly under-prepared to teach science (Appleton, 2002, 2003; Bayer Corporation, 2004; Bleicher, 2007, 2009; Harlen, 1997; Harlen & Holroyd, 1997; Howitt, 2007; Palmer, Dixon, & Archer, 2015). This study examines the effect of an intervention that investigated the knowledge and understanding of science concepts for a group of eight first year preservice primary teachers. The intervention consisted of engaging the participants using two technology-based resources: Omosa, a 3D game-like virtual learning environment (VLE), and Omosa NetLogo, a simulation/modelling environment. A small-N study design was used in this study to determine whether or not the intervention resulted in improving preservice teachers' science content knowledge. Data sources included semi-structured interviews and concept maps. Overall, the findings suggest that the combination of the immersive and modelling environments facilitated and provided appropriate knowledge-building opportunities for participants by supporting their cognitive engagement.

Key words: immersive environments, modelling environments, primary preservice teacher education, inquiry learning, science education

Introduction

The high-quality teaching of science in primary schools is a national priority in Australia. The aim of this priority is to support young learners in becoming scientifically literate adults, as well as being able to contribute to both the social and economic wellbeing of Australia (Peers, 2006). Scientifically literate individuals should be able to use existing scientific knowledge to obtain new knowledge; explain scientific issues; draw conclusions about social issues related to science; make informed decisions for resolving problems related to science; understand how science might influence our material, intellectual and cultural environments; and engage in science-related issues (OECD, 2010). Hence, science is an important part of an individual's education. Reflecting this importance, the Australian primary school teaching curriculum positions science as one of the key learning areas (KLAs) in the primary education field, which means it is a compulsory curriculum component for all primary education students.

Widespread concerns, however, regarding primary school science education have been raised in research (see, e.g., (Appleton, 1999; CBI, 2015; Fitzgerald & Smith, 2016; Hackling, Peers, & Prain, 2007). It is argued that two central issues negatively affect the quality of science education in primary schools. The first is the limited time devoted to teaching science in primary schools (Angus, Olney, & Ainley, 2007; Appleton, 2002; Australian Science Teachers Association, 2014). The second is that the practices that teachers use in their science classes have been shown to influence students' scientific knowledge and skill development (Appleton, 2002; Harlen & Holroyd, 1997; Thornburg, 2009). These two issues are not new, but they appear to be increasingly problematic and are affecting the quality of science education in primary schools, and, as a consequence, students' educational outcomes.

Reviewing the literature related to science education in primary schools shows that primary teachers' science content knowledge is among the factors influencing science education in primary schools and causing these issues. Limitations to primary teachers' science content knowledge can cause primary teachers to avoid science instruction or to allocate less time for teaching science in the primary curriculum (Appleton & Kindt, 2002; Hoban, Macdonald, & Ferry, 2009; Naidoo, 2013). Insufficient content knowledge tends to have an effect on teachers' instructional approach as well (Kallery & Psillos, 2001). Scientific thinking approaches are often absent in teaching when teachers lack science content knowledge (Pine et al., 2006).

It is argued in this paper that students taught by teachers with limited content knowledge in science will most likely receive poor preparation and have poor learning experiences in school. Thus, strategies must be implemented to strengthen primary teachers' content knowledge in science. This paper will put forward the results of an intervention designed to develop preservice primary teachers' scientific content knowledge through the use of an immersive environment and a modelling environment. The research question that underpinned the study was: What is the effect of an intervention using an immersive environment (Omosa) and a modelling environment (Omosa NetLogo) on the development of first year preservice primary teachers' knowledge and understanding in science?

Background

Preservice teacher science education

Teachers are responsible for making decisions about the instructional approach that will provide the best learning outcomes for their students. To be effective and successful science teachers they are expected to understand science content and learning and teaching approaches; and to be able to combine this knowledge for teaching science (Garbett, 2011). Primary teachers are often trained as generalist teachers during teacher education programs; thus they are expected to develop skills necessary to competently teach multiple subjects across the primary curriculum, including science, to a diverse range of learners (Fitzgerald & Smith, 2016; Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2013; Timms, Moyle, Weldon, Mitchell, & Australian Council for Educational, 2018).

Primary teachers' science content knowledge is an ongoing concern in science education and has been well documented in Australia and internationally. Numerous studies have acknowledged that many primary teachers lack adequate science content knowledge to teach science efficiently (Akerson, 2005; Appleton, 2002, 2003, 2008; Appleton & Kindt, 2002; Davis, Petish, & Smithey, 2006; Harlen, 1997; Hoban et al., 2009; Nowicki et al., 2013; Oh & Kim, 2013; Trygstad, Smith, Banilower, & Nelson, 2013), resulting in science content knowledge being viewed as a challenge for primary teachers. For example, in an extensive review of the literature related to challenges facing preservice and early-career science teachers, Davis et al. (2006) identifies several challenges facing science teachers and organises them along five themes as challenges related to understanding (1) content and disciplines of science; (2) learners; (3) instruction; (4) learning environments; and (5) professionalism. The most salient challenge was the respondents' lack of understanding of science. This reflects an earlier study by Rennie, Goodrum, and Hackling (2001) about the status and quality of teaching and learning of science in Australian schools, which revealed that primary teachers' most cited factor was their lack of background knowledge affecting their teaching of science.

A survey conducted in Australia asked 102 primary school teachers from eight schools to rate themselves against critical areas of science and mathematics teaching. The results showed that less than 48% rated their knowledge of science content as good or very good, whereas 90% rated their knowledge of mathematics content as good or very good (Victorian Auditor-General, 2012). A US national survey conducted in 2013 into the current status of elementary science education in the country found that only around one-third of teachers felt that they were very well prepared to teach both life science and earth science and only 16% felt that they were very well prepared to teach physical sciences (Trygstad et al., 2013).

Other studies have examined and assessed primary teachers' science content knowledge in different ways and reported it as inadequate. For example Nowicki et al. (2013) utilised a mixed methods approach using both survey and observational data to examine the classroom teaching practice of preservice teachers during their science methods course and during their student teaching year, and also examined a science lesson taught by each student's cooperating teacher. Results revealed that 11 participants including both preservice and in-service teachers failed to deliver accurate science content to the class (these teachers presented lessons with less than 70% science content accuracy). They provided inaccurate explanations of the science concepts they taught and struggled to correct student misconceptions.

Garbett (2003) also provided evidence that, in general, the preservice teachers' subject knowledge in science was poor. Garbett (2003) investigated conceptual knowledge of science for 57 first year preservice teachers enrolled in a bachelor of education degree in New Zealand. The study used questionnaires and a science knowledge test to determine preservice teachers' actual and perceived competence in science content knowledge covered the four strands in the curriculum document: biology, chemistry, physics and astronomy. Preservice teachers were also asked to predict the number of correct answers they had made in each of the four strands. The results highlighted that many preservice teachers had poor understanding of science. It also emerged that the preservice teachers were unaware of how little they knew in science: there was a weak correlation between their perceived competence and the actual competence as measured by the test in the study. Research has shown that primary teachers (both preservice and in-service) and students do not possess adequate understanding of the nature of science (Leden, Hansson, Redfors, & Ideland, 2013; Lederman, 2007). It has been suggested that explicit emphasis on, and the inclusion of nature of science in teacher education programs and in teacher professional development, could help teachers develop approaches to the teaching of the nature of science in their classrooms (Leden et al., 2013).

Using technology primary teacher education programs

There have been many studies on the use of information and communication technology (ICT) in preservice teacher education. These studies have explored a range of areas, such as TPACK, English language, self-efficacy, Web 2.0, digital literacy and communication (L. Gill & Dalgarno, 2017; Hammond et al., 2009; Oz, 2015; Parr, Bellis, & Bulfin, 2013). These studies all show that preservice teachers who have more exposure to and have acquired a higher level of technological skills during their teacher training are more willing to use technology in their classrooms. The key features of the new teaching and learning experiences suggested in this study for offering to preservice primary teachers during teacher education programs to improve their content knowledge in science, are that they support the integration and implementation of constructivist approaches to present and visualise abstract and complex ideas and concepts in reliable contexts; and enable and support learners to engage in the learning process. This makes the integration of ICT particularly suitable. The content aimed to be taught in the current study consists of ecology concepts and phenomena that are difficult to visualise in real life, which made the use of particular ICT resources (immersive and modelling environments) appropriate (Kamarainen, Metcalf, Grotzer, & Dede, 2015).

Immersive environments for scientific knowledge development

Immersive environments are designed to simulate real-world experiences (realistic visual displaying) through the use of computer graphics programs to generate 3D environments. The objects in these environment are designed to represent aspects of the physical world; however, they may be enhanced in some way for emphasis (Zhang & Kaufman, 2013). It should be noted that there are myriad terms to describe an immersive environment. For example, in the literature they may be referred to as 3D environments, VLEs or multi-user virtual environments (MUVEs). In this paper, the term immersive environments was used for the sake of clarity. Immersive environments provide opportunities to interact with objects such as planets while collaborating with peers. MUVEs are immersive environments that enable multiple users to access the environment simultaneously over a server or the internet, and collaborate with other users simultaneously to participate in experiences integrating modelling and mentoring about problems similar to those in a real-world context (Duncan, Miller, & Jiang, 2012; Kamarainen et al., 2015). Immersive environments can be adapted to different disciplines; science education is one of the disciplines that uses immersive environments to support learning and teaching (Reisoğlu, Topu, Yılmaz, Karakuş Yılmaz, & Göktaş, 2017; Zhang & Kaufman, 2013). Several immersive environments and MUVEs have been designed and used for this purpose. EcoMUVE (Metcalf, Kamarainen, Tutwiler, Grotzer, & Dede, 2011), River City (Dede, Nelson, Ketelhut, Clarke, & Bowman, 2004), Quest Atlantis (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005) and Omosa (Jacobson, 2012) are examples of some of these environments that empower learners to engage with concepts within computer environments that aim to mimic important features of reality (Grotzer et al., 2016). In biology, for example, researchers have pointed to immersive environments as valuable technologies for education in supporting students' learning (Metcalf et al., 2011; Patridge, 2003; Tranter, 2004). In ecology specifically, a variety of immersive environments have been developed to support learning in ecosystems and are seen as an effective teaching aids for helping students accomplish a deeper understanding of ecosystem concepts (Kamarainen et al., 2015; Metcalf, Clarke, & Dede, 2009; Richards et al., 2012). Encouraging positive learning outcomes from implementing immersive environments in a variety of projects and areas have been shown. Findings include enhancing students' understanding of particular ecosystem concepts such as complex causal relationships in ecosystems (Metcalf et al., 2011); transferring complex ecosystems concepts (Grotzer et al., 2015); and enhancing students' motivation (Dede, Ketelhut, & Nelson, 2004; Nelson & Ketelhut, 2007) and engagement (Dede, Clarke, Ketelhut, Nelson, & Bowman, 2005a, 2005b; Dede, Nelson, et al., 2004; Kamarainen et al., 2015; Ketelhut, 2007).

Several immersive environments have been designed and used in K–12 education and their effects on students' understanding of science investigated (Grotzer et al., 2015; Metcalf et al., 2011). However, limited studies have examined the use of these environments in primary teacher education programs to teach preservice teachers science concepts and investigate their effects on preservice teachers' science content knowledge. In fact, most studies of preservice teachers have given more attention to the potential for utilising immersive environments in their teaching in the future; that is, they experienced these environments and then their perceptions about and attitudes towards the use of these environments in their future teaching were explored (Kennedy-Clark, 2011; Nussli, Oh, & McCandless, 2014; Sardone & Devlin-Scherer, 2008).

Modelling environments for scientific knowledge development

In this study, two environments were engaged in order to harness the learning potential of both environments. In this respect, computer simulations and modelling differ from virtual reality. Brey (2008) states that the aim of computer simulations usually is not to undertake realistic visual modelling of the systems they simulate, unlike in virtual reality. Instead the graphical representations usually include only the features that are relevant for the purposes of the simulation. Another difference is that computer simulations do not need to be interactive; typically, the user will determine a number of parameters at the beginning of a simulation and then run the simulation without any further involvement in the process (Brey, 2008). Computer modelling is also being used increasingly in education and training. In science education, for example, computer modelling approaches have been used in several educational research projects (Gobert et al., 2004; Jacobson & Kozma, 2000; Wilensky & Reisman, 2006) to help school students understand complex systems in different fields in the sciences, such as physics and biology. They have shown to be successful at helping students develop a deep understanding of evolving phenomena (Dickes, Sengupta, Farris, & Basu, 2016; Sengupta, Kinnebrew, Basu, Biswas, & Clark, 2013). However, there has been very few studies on the use of modelling environments in primary teacher education programs to teach preservice teachers science concepts and their effect on preservice teachers' science content knowledge. As with immersive environments, studies using modelling environments with preservice teachers during their education program are more focused on preparing them to use computer modelling in their classrooms in the future (Schwarz, Meyer, & Sharma, 2007).

Research Design

To achieve the aims of the research, an intervention was designed and applied on a group of eight preservice primary teachers. The participants in the study were a group of preservice teachers that had low prior background in science. A demographic survey was designed by the researcher and used to identify and recruit appropriate participants. The criteria for involvement were students with low confidence in their ability in science and limited formal study of science. The survey included questions about gender, current level of confidence in ability in science on a scale from 1 (lowest) to 10 (highest) and science courses studied in Years 11 and 12 at school, and at university. The survey was administrated to all preservice teachers in the first year of their enrolment in the bachelor of education primary degree at an Australian university undertaking a core science subject that all students must complete. The intervention consisted of engaging the participants in learning with two technology-based resources: Omosa, a game-like immersive environment, and NetLogo, a simulation/modelling environment.

A qualitative small-N study research design, also known as a single-subject (McDougall & Smith, 2006) or single-case design (Lobo, Moeyaert, Baraldi Cunha, & Babik, 2017), was utilised for this study. The small-N design offers an alternative to large group designs (Alnahdi, 2015; Lobo et al., 2017); where N can be an individual or a group of individuals (Engel & Schutt, 2016). The approach in small-N design research involves sequential observations of studied individuals or groups before, during and after an intervention (Graham, Karmarkar, & Ottenbacher, 2012). Each participant/group serves as their own control, which means there is no need for a control group (Cakiroglu, 2012). Researchers and educators use this type of design as a tool to examine and document the effectiveness of an intervention for participant/s (Alnahdi, 2015; Rassafiani & Sahaf, 2010) when there is a limited number of participants (Rassafiani & Sahaf, 2010). The small-N design is increasingly used in health and rehabilitation research(Barnett et al., 2012; Graham et al., 2012); however, as indicated by (Gouvea, 2017), the value of small-N design in the social sciences is contested by many scholars. (Gouvea, 2017) refers to recent papers (e.g. (Jaber & Hammer, 2016; Quan & Elby, 2016) that illustrate how small-N studies can make contributions to education research and practice.

Determining what happened in this small number of individual cases was of particular value here. Therefore, the small-N design was chosen over larger sample size designs as the focus of the study was this particular group of preservice teachers and not the whole cohort of first year preservice teachers. Variation in individual responses will always exist (Dugard, File, & Todman, 2012) and small-N designs attempt to examine elected cases in depth, rather than making claims based on large numbers (Gouvea, 2017).

Virtual and Immersive Environments

The intervention designed for this study involved participants' engagement with learning in two technology-based resources over two learning sessions. The first session involved the use of Omosa, the immersive environment and the second session involved the use of Omosa NetLogo, the modelling environment. Omosa and Omosa NetLogo were collaboratively designed and developed by the University of Sydney and Macquarie University. These two resources aimed to teach participants some ecology concepts related to conceptual dimensions of ecosystems and food webs that line up with the new Australian science curriculum, as well as the main phases of conducting scientific inquiry (e.g., hypothesis generation, dependent and independent variables, data collection, analysis and interpretation, reporting) (Jacobson et al., 2011). The teaching was based on constructivist teaching practices that emphasise active and collaborative learning and provide opportunities for learners to discover and construct new knowledge based on their prior knowledge and understanding from previous experiences (Zhao, 2003). In Omosa and Omosa NetLogo, participants followed the scientific method where they were able to test hypotheses using Omosa NetLogo models based on observations made in the Omosa game-like virtual environment by manipulating different variables and observing the results. Figures 1 and 2 are screenshots from Omosa and Omosa NetLogo, respectively.

Figure 1: Screenshots from Omosa environment

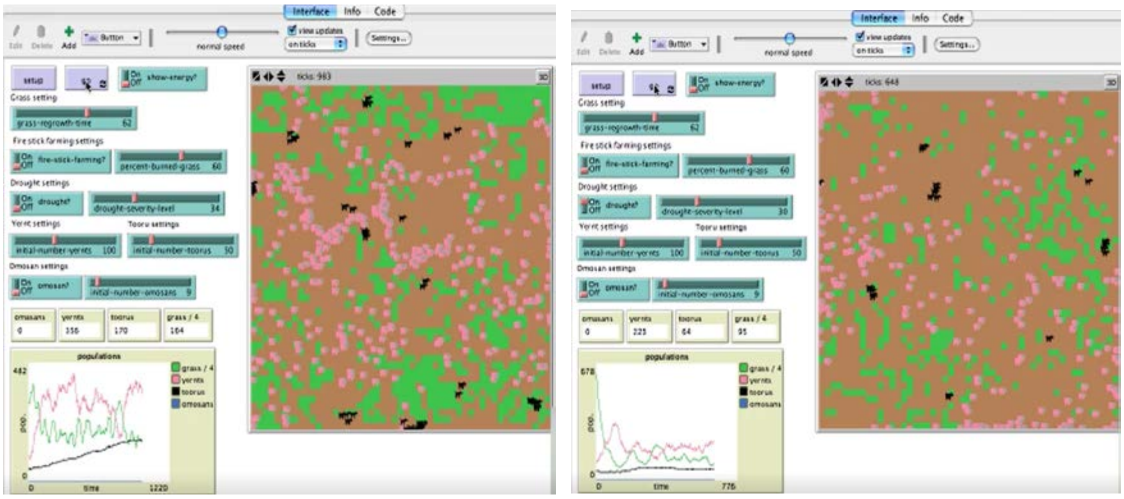

Figure 2. Screenshots from Omosa NetLogo environment

Participants

The study involved a group of eight pre-service teachers studying primary teacher education at a metropolitan university in Sydney. The participants worked in dyads during the intervention.

Data Collection and Analysis

A variety of data sources and methods was used to develop a richer understanding of the influence of the study intervention on participating preservice primary teachers' knowledge and understanding of science concepts. Data were collected from (1) four semi-structured interviews, two long (pre-test and post-test) and two short interviews; (2) participants' concept maps (pre-test and post-test concept maps included in the interviews); and (3) participants' responses recorded in their guidebooks.

The use of semi-structured interview is one of the most common methods of data collection in qualitative research to explore individual participants' experiences, opinions, views and motivations (P. Gill, Stewart, Treasure, & Chadwick, 2008). Four semi-structured interviews, two long and two short, were conducted. The long interviews were developed and conducted as pre-test and post-test interviews and a short interview was conducted at the end of each learning resource session. All interviews were audio recorded and transcribed for data analysis.

Concept maps formed a rich source of data in this study. In the concept map-constructing question, participants were provided with a list of common ecological terms (selection of terms was based on recommendations from Dr Taylor) and asked to use as many of the terms as they could to construct a concept map about the adverse effects on animals in an area. Based on Bloom's taxonomy (Bloom, 1956) this question was a higher cognitive level question that allowed learners to demonstrate their knowledge and understanding to show their ability to make use of knowledge (application). The number of links created, the amount of time spent and the number of groups (clusters) of concepts in the concept map were recorded for pre-test and post-test concept maps. The numbers were compared between pre-test and post-test sessions to identify any differences in these numbers with participants' experiences in the study. The number of links in each concept map was found by summing the number of links to and from each concept. The time spent constructing each concept map was determined by recording the start and end time for each concept map. The concept clusters were identified visually using the principle of proximity, with assistance from a biology expert. A group of concepts was considered a cluster if participants placed those concepts close to each other and organised them in a way that revealed their connectedness (similar to a unit).

The assumptions for the above are: creating more accurate links in a concept map is an indicator of improvement in participants' knowledge and understanding. The total number of relationships/links is an indicator of how well a knowledge base is structured (Schaal, Bogner, & Girwidz, 2010). Creating more accurate links in less time means that participants gained more knowledge and understood the materials better, so they needed less time to construct the concept map. How participants make connections between concepts and how they cluster groups of concepts together is an indication of their understanding (Gericke & Wahlberg, 2013) as it represents their understanding of the interrelationships and connections among concepts. A reduction in the number of clusters in post-test concept maps means that there is a higher level of grouping of interrelated concepts into one cluster, suggesting that participants know more than isolated facts about the topic and can grasp relationships among different concepts.

The concept maps were analysed qualitatively in order to track the level of participants' understanding during the study. In this method, each concept map was analysed by classifying the content and the structure of the concept map according to the different levels of the SOLO taxonomy. The SOLO taxonomy was first described by Biggs and Collis (1982). Biggs (1996) explains SOLO as 'a means of classifying learning outcomes in terms of their complexity, enabling us to assess students' work in terms of its quality not of how many bits of this and of that they have got right'. SOLO taxonomy levels offer a systematic way of describing how a learner's performance grows in complexity when mastering new learning (Biggs, 1996). An assessment matrix for participants' understanding was created for this study based on Fetherston (2007). All participants' concept maps were analysed using the created assessment matrix, where both the generation process and the finished products of the pre-test and post-test concept maps were assessed. The SOLO levels identified in the created assessment matrix were applied to track and assess the progress of participants' knowledge and understanding of the presented materials by comparing assessment results between pre-test and post-test concept maps. In the concept map-constructing question, participants were provided with a list of common ecological terms (selection of terms was based on recommendations from Dr Taylor) and asked to use as many of the terms as they could to construct a concept map about the adverse effects on animals in an area. Based on Bloom's taxonomy (Bloom, 1956) this question was a higher cognitive level question that allowed learners to demonstrate their knowledge and understanding to show their ability to make use of knowledge (application).

Two guidebooks were developed for this study to help participants organise their learning and to make meaning from the learning experiences. Different activities and tasks were developed following the '5Es' (engage, explore, explain, elaborate and evaluate) learning cycle model (Bybee, 1997) and arranged in a way intended to promote the building of participants' knowledge and understanding. In addition to the role of the guidebooks in supporting participants' learning from the two technology resources, the guidebooks were utilised as a data collection source for data related to participants' knowledge and understanding. The knowledge and understanding data were collected from the guidebooks to assess participants' knowledge and understanding. To accomplish this, the synthesis question, which was developed originally for the explain phase of the 5Es model was used to assess participants' knowledge and understanding. The question allowed participants to demonstrate their knowledge and understanding and show their ability to integrate their knowledge. It measured their ability to synthesise information from the learning resources to assess their knowledge. The content of the participants' responses to this question should be based on the content of the learning environment about which the question was asked, to measure and track their knowledge and understanding in each session.

Research Phases

The intervention was staged in two sessions with the participants. After allocating the dyads the intervention was introduced over two sessions with one dyad at a time. Figure 3 shows the overall design of the study presenting the sequence of the study over the two sessions and the data collection instruments.

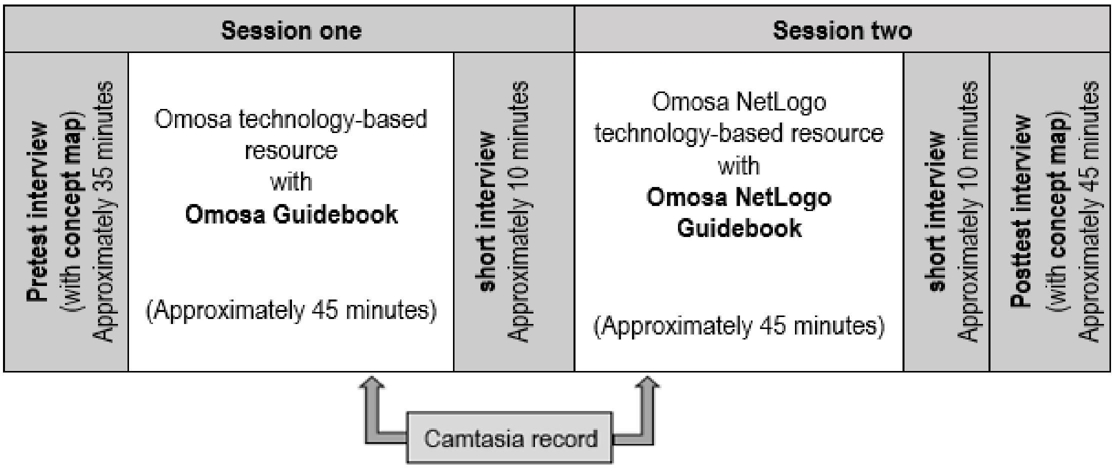

Figure 3. An overall design of the study

The pre-test interview was performed at the beginning of session one for approximately 35 minutes. The immersive environment Omosa, installed on a computer, was then introduced to the participants to work on for approximately 45 minutes. The Omosa guidebook was provided and participants were asked to write their responses to the different tasks in the space provided. At the end of session one, the Omosa short interview was conducted for approximately 10 minutes. In session two, the modelling environment, Omosa NetLogo, also installed on a computer, was introduced to the participants to work on for approximately 45 minutes. The Omosa NetLogo guidebook was provided and participants asked to write their responses to the different tasks in the space provided. The Omosa NetLogo short interview was then conducted for approximately 10 minutes. At the end of this session the post-test interview was conducted for approximately 35 minutes. The interviews were conducted with each dyad of participants by the researcher. The knowledge and understanding assessment data were all composed collaboratively within the dyads. During the pre-test/post-test interviews a sheet of paper with a written version of the assessment question asking participants to construct a concept map was handed. All groups were provided with the same set of terms and were free to generate their own links and labels to construct their concept maps. Each term was printed on a small card and all cards were given to participants along with a large sheet of paper to construct a concept map. The guidebooks included a space for participants to record their responses.

Results

The results present the findings of each dyad in relation to the data sources. To obtain more data about the changes in participants' knowledge and understanding the pre-test/post-test concept maps were first analysed quantitatively and then qualitatively and the guidebooks synthesis questions were analysed qualitatively. Analysis of the participants' concept maps quantitatively captured three pieces of evidence of change in knowledge and understanding. First, comparison of the pre-test and post-test concept maps revealed that all dyads created more connections/links between ecosystem concepts in the post-test concept map than in the pre-test concept map (Table 1). Second, there was a reduction in the time spent by dyads creating post-test concept maps. All dyads created more links in their post-test concept map in a shorter time (Table 1).

Table 1. Number of connection/links between ecosystem concepts created by the dyads in the pre-test and post-test concept maps

Group	Pre-test concept map		Post-test concept map	
	# of links	**Time Approx.**	**# of links**	**Time Approx.**
G1 (Aimee and Tina)	38	14	59	7
G2 (Kristy and Alice	23	10	34	8
G3 (Mia and Lina)	17	16	22	10
G4 (Elisa and Mary)	21	18	22	15

Third, a visual analysis of the structure of the pre-test and post-test concept maps based on the definition of the cluster of concepts identified for this study, showed a decrease in the number of clusters of concepts. Comparison of the pre-test and post-test concept maps showed that three of the four dyads had organised the concepts in their post-test concept map into fewer clusters than in their pre-test map. The fourth dyad had organised the concepts in their post-test concept map into the same number of clusters as in the pre-test concept map, with slight changes in the arrangement of concepts in each cluster (Table 2).

Table 2**.** Number of clusters dyads organized the concepts in pre-test and post-test concept maps

Group	Number of clusters in Pre-test concept map	Number of clusters in post-test concept map
G1 (Aimee and Tina)	3	2
G2 (Kristy and Alice)	3	3
G3 (Mia and Lina)	2	1 cluster with central theme around human impact and natural causes
G4 (Elisa and Mary)	2	1 cluster with central theme

Qualitative analysis of the pre-test/post-test concept maps by applying the SOLO taxonomy and comparing the outcomes for each dyad revealed a shift in the level of understanding from the SOLO pre-structural, uni-structural and multi-structural levels in pre-test concept maps to multi-structural, relational and extended abstract levels in post-test concept maps (Table 3).

Table 3. SOLO levels for each dyad in the pre-test and post-test concept maps

	Pre-test		Post-test	
Group	**Number of clusters**	**Solo Level**	**Number of clusters**	**Solo Level**

G1 (Aimee and Tina)	3	Uni-, Pre-, and Multi-structural	2	Relational and Extended Abstract
G2 (Kristy and Alice)	3	Multi-structural	3	Multi-structural
G3 (Mia and Lina)	2	Multi-structural	1 cluster with central theme around human impact and natural causes	Relational
G4 (Elisa and Mary)	2	Multi-structural	1 cluster with central theme	Relational with some Extended Abstract

G1 (Aimee and Tina). In their pre-test concept map, Aimee and Tina arranged the concepts in three clusters. Connections between some concepts were missing and some connections were simple and obvious, so the map is classified as pre-structural and uni-structural (Figure 4)

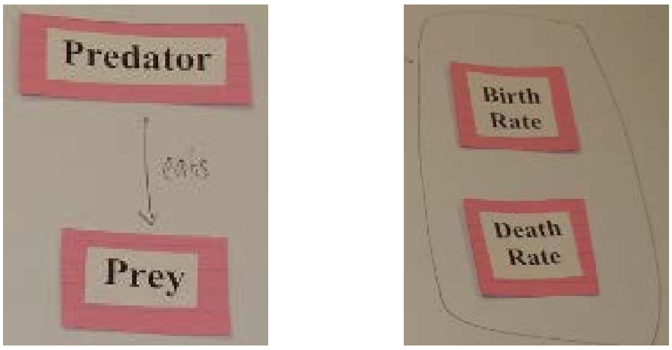

Figure 4. G1 pre-structural and uni-structural levels in the pre-test concept map

However, in the post-test concept map they arranged the concepts in two clusters and more complicated interactions were evident. Participants integrated their understanding from both sessions, made new connections and moved away from a series of linear pre-structural relationships to a more dynamic way of thinking about system relationships over time (Figure 5), classified as relational and extended abstract levels.

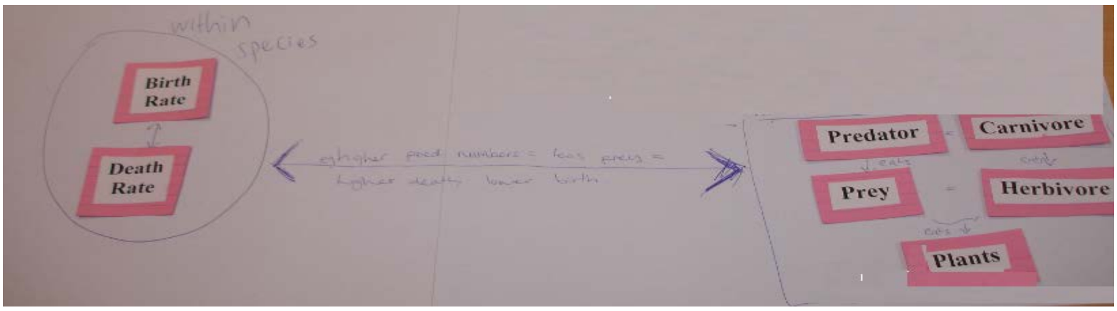

Figure 5. G1 relational and extended abstract levels in the post-test concept map

G2 (Kristy and Alice). In their pre-test concept map, Kristy and Alice arranged the concepts in three clusters and provided a number of connections between several concepts within and between clusters that are directly related. They then connected some of the concepts from each cluster to a central theme that they called ‘EXTINCTION’, classifying the organisation as multi-structural (Figure 6).

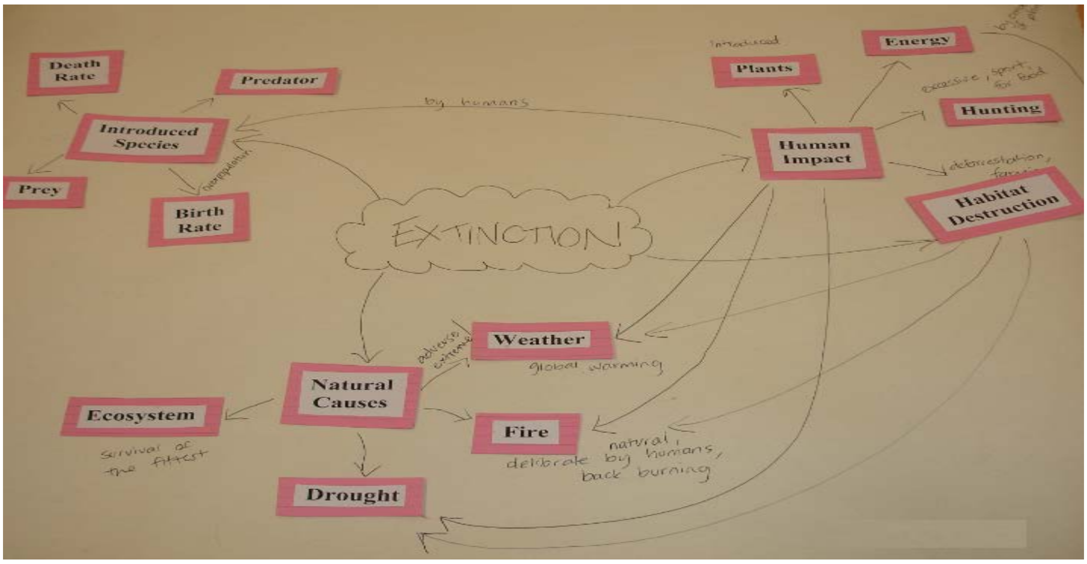

Figure 6. G2 multi-structural level in the pre-test concept map

In the post-test concept map, the ‘EXTINCTION’ theme and same number of clusters were retained but more links were created between concepts with a slight change in the arrangement of the concepts in each cluster. There was little change between pre-test and post-test concept maps and little evidence of an effect of the intervention in the dyad’s post-test concept map. Thus, this map is classified as multi-structural (Figure 7).

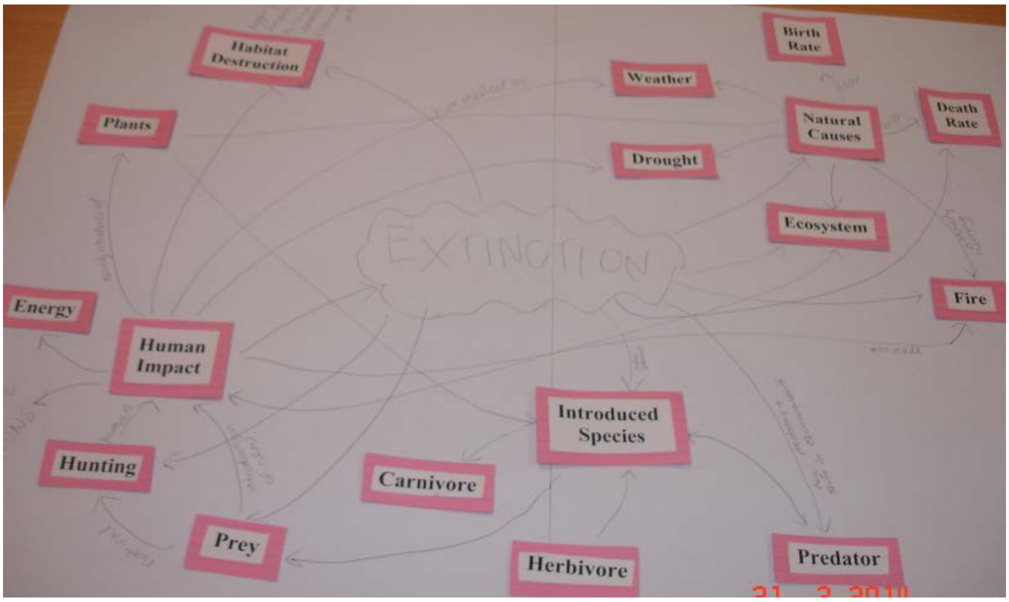

Figure 7. G2 multi-structural level in the post-test concept map

G3 (Mia and Lina). In their pre-test concept map, Mia and Lina arranged the concepts in two clusters and provided a number of connections between several concepts that are directly related. However, few explanations were provided about each link and no focal point was clear, leading to a multi-structural classification (Figure 8).

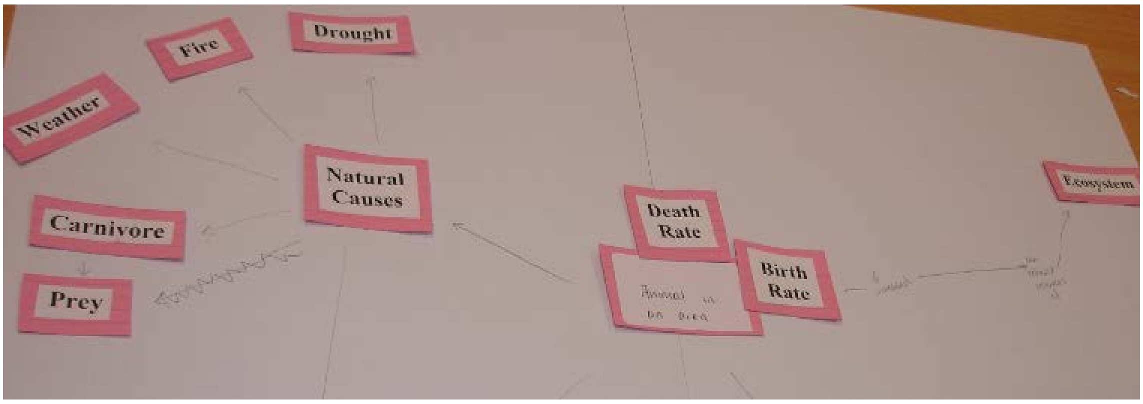

Figure 8. G3 multi-structural level in the pre-test concept map

In their post-test concept map, they arranged the concepts in one cluster and provided good examples of relationships that indicated their understanding of interactions. Input from the intervention was obvious in their post-test concept map, which is classified as relational (Figure 9).

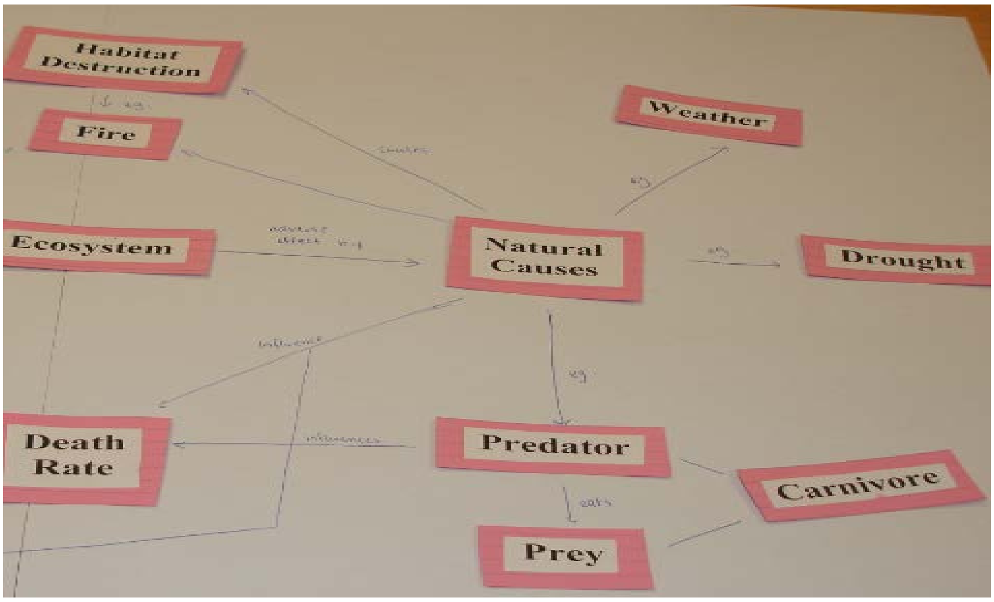

Figure 9. G3 relational level in the post-test concept map

G4 (Elisa and Mary). In their pre-test concept map, Elisa and Mary arranged the concepts in two clusters with sensible relationships and explanations, demonstrating appropriate use of simple theoretical everyday terms. The concepts are well organised but the links are not justified and the central theme is not clear, leading to classification as multi-structural (Figure 10).

Figure 10. G4 multi-structural level in the pre-test concept map

In their post-test concept map, they arranged the concepts in one cluster and provided sensible links to central and peripheral concepts—for example, ‘Herbivore > plants’—with better justification and integration, However, they still used descriptive and everyday terms, so that the result was more like an essay, which classifies it as relational with some extended abstract levels (Figure 11).

Figure 11. G4 relational with some extended abstract levels in the post-test concept map

For the guidebooks assessment (synthesis) questions about what had caused the decline in the populations of animals on Omosa, participants’ responses included at least two main points in the context of each environment, along with reasons and examples of each (Table 4).

Table 4. Number of factors included in the dyads’ responses for the assessment (synthesis) question in each guidebook

Group	Number of the main points mentioned in the synthesis question from	
	Immersive environment (Omosa)	Modelling environment (Omosa NetLogo)
G1 (Aimee and Tina)	3	3
G2 (Kristy and Alice)	5	4
G3 (Mia and Lina)	3	2
G4 (Elisa and Mary)	3	2

Applying the SOLO taxonomy to dyad responses to the synthesis questions revealed a shift in understanding for all groups, as shown in Table 5.

Table 5. SOLO levels for each dyad in the assessment (synthesis) question in each guidebook

Group	SOLO level for responses to synthesis questions in the immersive (Omosa) and modelling (Omosa NetLogo) guidebooks			
	Omosa	**Explanation**	**Omosa NetLogo**	**Explanation**
G1	Multi-structural and relational	Providing number of factors; demonstrating relationships and justifying their answers; their response has some good explanations of causes for the issue; they are thinking quite holistically	Relational and extended abstract	Making arguments with evidence, examples and justification; listing different terms that are more technical/scientific and related to overarching concepts/biological systems; much clearer relationships; incorporation of Omosa and Omosa NetLogo is shown; more precise thinking after using Omosa NetLogo; ‘thinking like scientists’
G2	Multi-structural and relational	Providing a number of factors; demonstrating relationships; thinking laterally and providing evidence	Relational and extended abstract	Making predictions, recommendation and interpretations based on their ‘experimental results’
G3	Multi-structural and relational	Consistent listing, providing a number of factors and evidence with some justification; difficult to precisely identify the level but at least relational	Multi-structural	Providing a number of factors
G4	Multi-structural	Providing a number of factors	Relational and extended abstract	Following later stages of scientific method; discussing concept of ‘no right answer’ and justifying the changes in relationships. In the scientific method these are good examples of the first stage of making observations

Table 6 shows the changes in the SOLO levels for each dyad throughout the two sessions.

Table 6. The development in SOLO levels for each group throughout the two sessions

Group	SOLO level			
	Pre-test concept map	**Immersive guidebook synthesis question**	**Modelling guidebook synthesis question**	**Post-test concept map**
G1 (Aimee and Tina)	Uni-, pre- and multi-structural	Multi-structural and relational	Relational and extended abstract	Relational and extended abstract
G2 (Kristy and Alice)	Multi-structural	Multi-structural and relational	Relational and extended abstract	Multi-structural
G3 (Mia and Lina)	Multi-structural	Multi-structural and relational	Multi-structural	Relational
G4 (Elisa and Mary)	Multi-structural	Multi-structural	Relational and extended abstract	Relational with some extended abstract

Moreover, analysis of dyad responses to the questions in the pre-test and post-test interviews (‘If someone asked you “What do scientists do?” what would you tell them?’ and ‘How do scientists go about understanding what causes animals to become extinct?’) showed that in post-test, all dyads used more scientific language in their responses. Table 7 provides examples of participants’ responses to the two questions in the pre-test and post-test interviews.

Table 7. Participants’ responses to the questions: ‘What do scientists do?’ and ‘How do they go about understanding what causes animals to become extinct?’

Question	Pre-test	Post-test
G1 (Aimee and Tina)		
1. If someone asked you “What do scientists do?” what would you tell them?	*I guess they do experiments to help the world”, they will find you solutions to help, as well as testing things doing different, doing, like testing different circumstances to…. , you know, make the place a bit better.*	*they look at the relationships between things and then what impacts what”, “related to ecology: relationships between things like, you know, the impacts on each other and the animals then people and animals and other animals, animals and plants and stuff, say like the relationships and the impacts of those*
2. How do scientists go about understanding what causes animals to become extinct?	*I think they count how many in the world first and then they list it as in dangers if it falls below and put tags on them unless they are already extinct”, “I think they just follow and track what it does and check the health once in a while and see if it is depreciating and if it is they will follow, you know, what they do compared to something else that*	*They look at what is impacted them and then they look at how it impacted them and to what extinct and what factors had changed to make them going to extinct”, “they test animals in specific habitat and see which one is the healthiest and which one is seems to becoming weaker and then they will test more stuff*

	has health that still high and compare to the subject…..	
G2 (Kristy and Alice)		
1. If someone asked you "What do scientists do?" what would you tell them?	*A lot, I mean just from my aunty like she has a lot so she is actively involved is research and trying to get grant for the university and teaching and being a mentor and replying to many emails a day, doing admin", "if you had to give one sentence for the scientists someone actively investigating the world, how the world works and theorizing experimenting and observing, and also coming up with new ideas and then innovation getting rid of the old ideas so it is an ever changing discipline*	*Testing hypothesis and constantly reinventing a concepts and ideas about things that we think we already know*
2. How do scientists go about understanding what causes animals to become extinct?	*I mean with the scientists it is always testing hypotheses and testing everything when you have new ideas implementing the idea and if it is successful. If you talking about particular species I would mention that they study the species and their environment to see and observe exactly what happening and what could be the effects*	*Observations and experiments, yeah observation is probably the biggest one they can't really control drought or anything that we did in Omosa but by observation they can document and maybe create like one of those mathematical equations and graphs as well prediction, tagging of animals to catch more event to collect data that provide them with the information*
G3 (Mia and Lina)		
1. If someone asked you "What do scientists do?" what would you tell them?	*They find out the how's like how things work and they do all the tests and they do experiments to find out that*	They investigate the how's and whys of just general things, about things in the world around us, just how things work and why they work
2. How do scientists go about understanding what causes animals to become extinct?	*They do research, they have to look at what the animal needed when they were alive or what similar animals need when they are alive and then maybe how that wasn't provided to see like maybe that why they went extinct, if something that they need to stay alive was taken away so looking at the*	*Tracing population, and like so you have to trace population and I suppose that they have to hypothesize like factors that would influence and then also trace that, so say if it is drought then you trace the population in correlation with drought being present or not", "They also work like prior theories as well, I mean I don't know if there is a*

	environment at the time that they wouldn't have been alive	*prior theories in Omosa but they might already know*
G4 (Elisa and Mary)		
1. If someone asked you "What do scientists do?" what would you tell them?	*Research, hypothesis, experiments*	*investigate things* *they search, establish hypothesis and research it for any field*
2. How do scientists go about understanding what causes animals to become extinct?	*They go to where they live habitat and understand the area that they lived in, the foods that they eat, and like the other species around them, and the human population in therein*	*make a hypothesis and then like independent and dependent variables and then test it over period of time*

Several patterns arose from the analysis of responses to the assessment tasks, including pre-test/post-test concept maps and synthesis questions, for all dyads:

> **Better connections.** All dyads created more connections/links in their post-test concept map than in their pre-test concept map, and in a shorter time. Also, three out of four dyads organised and grouped the concepts in their post-test concept map into fewer clusters than in their pre-test concept map. The fourth dyad organised concepts into the same number of clusters in both the pre-test and the post-test concept map.
>
> **Shift in understanding (concept maps).** Comparison between the pre-test and the post-test concept map for all dyads indicate a shift in the level of understanding from SOLO pre-structural, uni-structural and multi-structural levels in the pre-test concept map, to multi-structural, relational and extended abstract levels in the post-test concept map.
>
> **Shift in understanding (synthesis question).** In their response to the guidebook synthesis questions all dyads were able to include at least two main points in the context of each environment as well as some reasons and examples. Applying the SOLO taxonomy to these responses identified a shift in the level of understanding from SOLO multi-structural and/or relational to multi-structural and/or relational and extended abstract.

Discussion

A change (gain) in participants' knowledge and understanding of ecology concepts was shown in all dyads, which would suggest learning had occurred in both environments, which may facilitated and supported participants' understanding of ecology concepts and provided appropriate knowledge-building opportunities that allowed these participants to acquire new knowledge. This result accords with findings reported by Jacobson, Taylor, and Richards (2016) of significant learning gains by participants when an immersive environment in conjunction with a modelling environment were used with secondary school students to help them learn general principles of scientific knowledge about biological systems.

The results of this study are generally consistent with prior research reporting a positive effect of immersive and modelling environments similar to Omosa and Omosa NetLogo on learners' science content knowledge. For instance, several studies reported learning gains in science-related areas using VLEs and game-like virtual environments (Anderson & Barnett, 2011; Barker & Gossman, 2013; Ketelhut, Clarke, & Nelson, 2010; Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014) and computer modelling environments (Blikstein & Wilensky, 2010; Wilensky & Reisman, 2006) separately. The findings in this study suggest that the combination of immersive and modelling environments was among the factors contributing to the improvement in participants' science content knowledge in this study. Because earlier studies that utilised the combination of such environments were limited and performed with secondary school students, it is difficult to make direct comparisons between this study and previous research.

Analysis of the dyads' responses to pre-test and post-test concept map question asked during interview, as well as their responses to assessment (synthesis) questions presented in each guidebook, indicates that all four dyads experienced improvement in their knowledge and understanding of ecology concepts during the intervention. Pre-test and post-test assessment results have been utilised in many studies to examine the effect of different interventions on preservice teachers' knowledge in science and science-related fields. Anderson and Barnett (2011), for example, used pre-test and post-test assessment scores to explore the effect of using a video gaming technology on preservice teachers' understanding and learning of physics concepts. Similarly, Baser (2006) used pre-test and post-test assessment scores to investigate the effects of using simulations on preservice primary teachers' understanding of physics concepts. Analysing participants' responses to the assessment tasks revealed better connections and shift in understandings.

A concept mapping tool was used to assess participants' learning outcomes (Novak, 2003; Rice, Ryan, & Samson, 1998)and monitor their learning progress (Kennedy-Jones, Naji, & Ennals, 2015) throughout the study. Using concept maps to collect data to assess changes in participants' science knowledge after their learning in two technology-based resources in this study is similar to the approach taken by Hoban et al. (2009). In their study, concept maps created by preservice teachers were analysed and compared from the beginning to the end of the study to monitor changes in their science content knowledge after they had used technology to learn science content. The reduction in the number of clusters in post-test concept maps—that is, the grouping of more interrelated concepts into one cluster—might be a result of gaining more understanding because clusters can be seen as a demonstration of learners' knowledge structures (Gericke et al., 2013). Organising concepts into bigger clusters might mean that participants hold more than isolated facts about a topic and can grasp relationships between different concepts. Thus, the participants organised their knowledge into a coherent whole and grouped more related concepts within one cluster as they became more aware of the relationships among concepts. Identifying improvements in participants' knowledge and understanding based on an increased number of ideas/concepts within a cluster is consistent with the National Research Council (2001), who state that normally the structure of learners' understanding is hierarchical; as learning increases, clusters of simple ideas accumulate into larger, more complex clusters. However, the changes in the total number of links and clusters between the pre-test and post-test concept maps did not distinguish between levels of understanding or provide details about how these changes had occurred. As Schwendimann (2014) points out, the total number of links and concepts provides little insight into a learner's understanding; a greater number of links does not mean that the learner understands the subject better. Therefore, to triangulate the results and achieve better insights into participants' development of understanding, an additional method was used to analyse and score these concept maps. An assessment matrix for the analysis was developed based on the SOLO taxonomy (Biggs & Collis, 1982) to qualitatively analyse the concept maps.

The participants' pre-test and post-test concept maps were analysed and assessed according to the levels of the SOLO taxonomy using a matrix developed for this study. The focus was on differences in structural complexity of concept maps (McPhan, 2008) that can be observed in participants' concept maps over time. Applying the levels of the SOLO taxonomy to the concept maps allowed assessment and examination of increases in participants' level of understanding of ecology concepts. The SOLO level considerably improved from pre-test to post-test concept maps for all groups, demonstrating an increase in structural complexity in participants' learning, shifting from a surface to a deeper understanding. The results showed how participants' understanding grew in complexity as they were learning. None of the pre-test concept maps were categorised as having a relational or extended abstract level of structure, while most of the post-test concept maps fell were categorised at the relational or relational and extended abstract level. This indicates that participants had grasped a higher level of ecology knowledge during the study, moving from a surface to a deeper level of conceptual understanding (Bakouli & Jimoyiannis, 2014). All groups showed, either in parts or the whole of their pre-test concept map, knowledge of different concepts and different relationships between these concepts; however, the relationships were not demonstrated, there was no clear central concept and it seemed that participants had difficulty identifying focal point or links, all of which indicate more concrete and surface-level understanding. This is in line with research pointing out that uni-structural and multi-structural responses reveal surface learning (Dudley & Baxter, 2009; Hattie & Brown, 2004).

Identifying improvement in participants' knowledge from surface to deeper knowledge based on a change in classification of their responses to assessment activities, from uni-structural and multi-structural SOLO levels to relational and extended abstract levels, supports research that has connected relational and extended abstract responses to the conception of deep learning, while uni-structural and multi-structural responses reveal surface learning (Dudley & Baxter, 2009; Hattie & Brown, 2004). Additionally, the analysis results for the synthesis questions showed that participants' responses included content related to what they had learnt in each technology-based resource. This included key concepts in the context of each technology-based resource in each of their responses. For example, in their response to the Omosa guidebook assessment question, all groups mentioned drought and firestick farming; three of the four groups also referred to hunting practices. These were all factors introduced in Omosa. Moreover, in their responses to the Omosa NetLogo guidebook assessment question it was clear that they had become more aware that no single factor causes a decline in populations of animals; it could be a combination of different factors. This also may indicate that participants had gained more understanding as they progressed through the study.

The improved levels of participants' understanding throughout the study were verified through the results obtained by analysing and triangulating the dyads' responses to the concept map question presented in the pre-test and post-test interviews and the assessment questions presented in the two guidebooks. The results were positive in regard to the students' learning in the immersive and modelling environments.

Conclusions

The qualitative small-N study design offered a mechanism for an in-depth study of the relatively small number of available participants. This design frame provided opportunities to gain an understanding of how technology-based resources and pedagogies embedded in these resources influence preservice primary teachers' understanding in science. It was clear from participants' comments that the combination of the two resources was useful in helping them understand and learn science concepts. The immersive and modelling environments had a positive effect on participants' knowledge mainly by supporting their cognitive engagement and collaboration, and providing an enjoyable and comfortable learning environment. One of the positive effects of using technology in education is the amplified intensity of student engagement; technology may be among the solutions required to increase the number of engaged students, and then increase their knowledge. The general consensus among participants was that the visual characteristics/representations of both technology learning resources had a positive effect on their overall learning experience and helped them understand and learn the content. By itself this offers support for the idea that both immersive and modelling environments should be utilised in teacher education programs to better prepare these future teachers for the demands of the 21st-century classroom.

Limitations of the Study and Areas for Future Research

This research has limitations. The target population consisted of a small number of first year preservice teachers enrolled in the bachelor of education primary degree at the University of Sydney, and because of the nature of the study the number of participants was small. Statistical generalisations from a small sample are by and large not valid. However, this shortcoming was addressed by utilising different data collection methods and sources to gain a better understanding of the effect of the study intervention, thus providing a basis for theoretical generalisation. Also there were only females in the study and that is due to the fact that there are almost only females enrolled in the Bachelor of Education primary degree.

Deeper misconceptions and fundamental epistemic beliefs as well as motivational dispositions are difficult to change with a short intervention. It would be worth conducting a longitudinal study to gain an understanding of knowledge retention. Replication of this study on a more diverse sample of students over a longer period might allow for more comprehensive results.

Future potential research areas include a longer study that follows preservice primary teachers from their first year through to the final year of their degree. It would also be useful to gain an understanding of how preservice primary teachers teach science when they are on professional experience. Another area of research would be to investigate the development of preservice teachers' TPACK as this would demonstrate their understanding of how to use technology to support their learning and teaching decisions.

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