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Investigating Remote Access Laboratories for Increasing Pre-service Teachers' STEM Capabilities

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ABSTRACT

Facing calls for greater emphasis on STEM education in primary school classrooms, teachers may be anxious because of limited exposure to STEM in their own education. The Australian Curriculum: Technologies is new and many teachers are not familiar with its content. Hence both in-service and pre-service teachers (PSTs) require preparation. This research used a case study method to investigate factors influencing PSTs' use of Remote Access Laboratories (RAL) with activities intended to develop their capacity to teach STEM in primary schools. Results highlighted the importance of PSTs' experience of STEM in their own education and showed the benefits of hands-on learning and scaffolding to support preparation of PSTs for teaching STEM subjects.

Keywords

Remote access laboratories, STEM education, Pre-service teachers

Introduction: STEM education

Achieving a productive and progressive future for Australia will require a workforce with high levels of scientific and digital literacy developed through studies of STEM (Science, Technology, Engineering and Mathematics) subjects (Office of the Chief Scientist, 2013). However, the Australian workforce has shortages of STEM graduates, including STEM teachers, caused by a decline in STEM study at the tertiary level, which flows on from a high dropout rate from STEM courses in high school (Freeman, 2013). In turn, the decline in STEM interest in high school has been attributed to inadequate time spent on STEM teaching and learning in primary schools (Office of the Chief Scientist, 2013).

STEM as a merged area of study, and especially the technology component, is new in primary schools but, based on the "scientific" nature of its content, likely to be similar to science which has been studied extensively. Primary teachers' reasons for lack of attention to science include limited exposure to science in their own education (Westerlund, Radcliffe, Smith, Lemke, & West, 2011), limited access to relevant teaching resources, and low confidence in their ability to teach science and technology effectively (Ping et al., 2011). Hence, it is important to support teacher professional learning to increase teachers' confidence to teach science and provide teaching resources for teaching science. Similar arguments can be advanced for technology and STEM.

Australian curriculum: Technologies

The Australian Curriculum: Technologies (ACARA, 2015) was developed to ensure all students benefit from learning about technologies that shape the world they live in (Falkner & Vivian, 2015). It consists of two distinct but related subjects: Design and Technologies and Digital Technologies (ACARA, 2015). It provides opportunities for students from Foundation (F) to Year 10 to develop their design thinking, computational thinking and related skills.

For most in-service and pre-service teachers, many of the elements in the Australian Curriculum: Technologies were not part of their own schooling or teacher preparation. They will be unsure about the relevant knowledge and skills and will lack the repertoire of teaching ideas that they have for more familiar subjects. Many primary school teachers are unfamiliar with the concepts of computational thinking and design thinking and consequently may be anxious about teaching the Technologies curriculum (Albion et al., 2016). To ensure the successful implementation of the curriculum, high-quality learning resources and activities are needed (Falkner & Vivian, 2015). Therefore, it is urgent to provide professional learning opportunities to build up primary school teachers' capacity and confidence to be able to teach the Australian Curriculum: Technologies.

Remote Access Laboratories (RALs)

Remote Access Laboratories (RAL) are well established in universities for providing students with more flexible access to experiments, especially in electrical and computer control engineering (Maiti, Maxwell, & Kist, 2013). RAL systems enable students to view and control equipment at a distance using cameras and sensors, and download real-time data in a computer laboratory, a classroom or at home (Tho & Yeung, 2016). They have been used effectively in secondary schools (Lowe, Newcombe, & Stumpers, 2013) and may also offer benefits for primary schools through sharing of equipment that is expensive to acquire and maintain. RAL has been used widely in engineering and computer science but there is little research on its application in other disciplines such as teacher education (Kist et al., 2014).

RALfie

The Remote Access Laboratories for Fun, Innovation and Education (RALfie) project was a joint effort between academics in Engineering and Education at University of Southern Queensland. Engineers were responsible for the technical aspects and educators provided pedagogical support (Kist et al., 2011). In traditional client-server RAL systems a university or other organisation hosts the RAL system and manages user access (Maiti, Kist, & Maxwell, 2015). In contrast, RALfie is a distributed RAL system with a modular design that allows participants to create and house experiments at distributed locations. The distributable feature makes RALfie more flexible for users (Kist et al., 2014). It expands the one-to-many approach, where one central laboratory serves many users, to a many-to-many approach, with many users using multiple equipment installations shared by various providers (Maiti et al., 2015). This project is unique because it provided both hands-on and remote activities that were incorporated into classes for preparing pre-service teachers to teach the Technologies curriculum as a medium for increasing their confidence with STEM activities. Pedagogical support provided by educators was important for the design of activities.

Hands-on learning

Piaget's developmental stage theory suggests that learning by children starts from the concrete and moves to the abstract (Piaget, 1974). Many educators believe that adults pass through similar stages when learning in new areas and learn best, especially when beginning in a new field, with concrete or hands-on experiences (Jacobs, 2001). Tinkering and making are powerful ways to learn because they allow makers to try out ideas, make adjustments and experiment with new things (Martinez & Stager, 2013). The tinkering approach is characterized by "a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities" (Resnick & Rosenbaum, 2013, p. 164).

Scaffolding

Constructivists argue that learning is an active process (Vygotsky, 1978). Students construct their understanding and knowledge based on their existing knowledge (Bryant et al., 2013). Scaffolding is a metaphor to explain guiding learning and development paths. It describes how teachers or peers supply students with the assistance they need to learn and then slowly withdraw help as students are capable of doing more independently (Jacobs, 2001). Scaffolded professional development is significantly superior to professional learning through self-study in terms of teacher beliefs and motivation, student performance and quality of instruction, and evidence shows that expert scaffolding in professional learning based on science curriculum has an advantage for primary teacher preparation for teaching science (Kleickmann, Tröbst, Jonen, Vehmeyer, & Möller, 2016).

STEM anxiety and its measurement

Science anxiety has been defined as a fear of, or aversion towards, science concepts, scientists, and science related learning activities (Sahin, Caliskan, & Dilek, 2015). Anxiety leads to panic, tension, and loss of ability to concentrate (Idowu, 2013). A large number of teachers required to teach STEM potentially have STEM anxiety (Bryant et al., 2013) which is detrimental to the effective teaching of STEM subjects in the classroom. The Positive and Negative Affect Schedule (PANAS) is a self-report measure assessing adult experiences of positive and negative affect (Watson, Clark, & Tellegen, 1988). There are twenty items, 10 each for positive (PA) and negative (NA) affect, related to various affective items which are adjectives describing mood states. A five-point

Likert-type scale is used by respondents to rate their mood against each item. The PA and NA have been identified as two dominant and relatively independent dimensions of the structure of affect (Watson et al., 1988), which can be used and analysed separately because they are two independent constructs (Hughes & Kendall, 2009).

Research context and problem

This research was conducted with PSTs enrolled in a final year course designed to prepare them for teaching the Australian Curriculum: Technologies in primary schools. The availability of RALfie offered an opportunity to provide them with enjoyable activities that had potential to alleviate anxiety about STEM through successful experiences. The study also enabled preliminary exploration of the potential of RAL for teacher development and use in primary schools, which is of particular interest in Australia where population centres and schools are often separated by significant distances.

Because the research was conducted in the context of an existing course, the time available for RAL activities was limited. Moreover, only 25 of the 168 students in the course were enrolled on the campus where they had direct access to the RALfie activities. The remainder were able to access the activities remotely via web browser. The study was conducted in a single semester during which all students had access to two online RALfie activities and those enrolled on campus could also participate in two face-to-face sessions.

The study explored PSTs' responses to the experience of working with the RALfie activities. This paper reports on the following research questions:

- What factors make a difference in pre-service teachers' experience of RAL?
- What can we learn from the RALfie experience to guide future use of RAL in primary education?

Research method

Quantitative methods have dominated analysis of anxiety since very early research. However, quantitative surveys are unable to provide specific reasons for changes in participants' emotional status. A solely quantitative approach is inadequate to explore the relationship between pre-service teachers' capacities for teaching STEM and engagement with hands-on and remote RAL activities. Additionally, the context of this study was complex because RAL was not the only intervention in the class. It was important to use a qualitative approach to attribute reasons to changes in pre-service teachers' emotional status.

The study used mixed methods. PANAS was used to assess PSTs' positive and negative affect scores before and after participating in RALfie activities. PSTs were also invited to volunteer for semi-structured interviews following completion of the RALfie activities. Difference scores calculated separately for PA and NA were used to identify PSTs' who had been interviewed for inclusion in case studies for deeper investigation of changes in their emotional states.

Case study allows deep analysis of individuals, especially with consideration of the individual's background, preconceptions and attitude. For this study, case study allowed deep analysis of the changes of confidence and emotional state resulting from the interaction with RALfie activities. The case study approach should help readers to understand the reasons for positive or negative change of PSTs' confidence and attitudes. Using multiple data sources is argued as a major strength of case study because it is more likely to generate accurate and persuasive findings based on a variety of evidence (Yin, 2009).

RAL experiences

The RALfie project offered PSTs maker events, which were face-to-face, and user activities, which were online. All PSTs in the course had access to the user activities but only the 25 students enrolled on campus could participate in the maker activities.

In the maker activities, participants used LEGO Mindstorms to assemble hands-on experiments and connect them to the RALfie system for remote access. Engineering academics assisted with setting up the maker activities and interacted with on-campus participants as they worked on the activities. Two maker events, each lasting two hours, were offered. In the first, PSTs were engaged in programming using Snap!, which is a free, graphical, drag and drop programming language (Garcia, Segars, & Paley, 2012). They learned how to use the Snap! language to program the LEGO EV3. Ready-made robots were connected to the server computers by the engineering academics. Students then used client computers to control the robots. In the second maker event, PSTs used the LEGO Mindstorms Kit to build robots, program their robot using Snap! and play robot soccer. Figure 1 shows the PSTs working with their robots and the completed robots playing soccer.

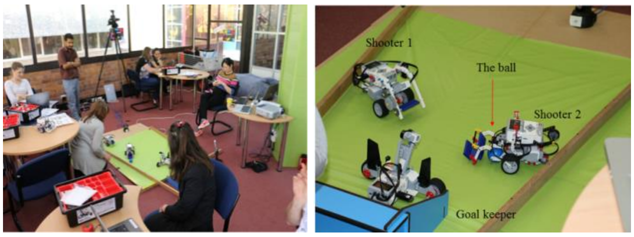

Figure 1. Robot soccer

In the user activities, participants, who included both on-campus and online students, were able to remotely operate experiments mounted in the Engineering laboratory. Two of the experiments being tested as part of the RALfie project development were selected as the basis for learning activities that could be undertaken by pre-service teachers. Both offered experience with remote operation of the equipment and had broader relevance to the technologies curriculum. Each was presented with step-by-step instructions with illustrations in a webpage within the course materials that included background information, links to relevant resources, and questions for reflection.

Figure 2 shows the Pendulum activity. It presents an apparatus in which a ball bearing could be raised or lowered to a selected distance from the pivot point and then pulled to one side and released using a mechanism constructed with LEGO. Recording the time required for a swing at different lengths enables exploration of the relationship between length and period of a pendulum and estimation of the gravitational constant. In practice PSTs did not have time for repeated trials so they were asked to raise the ball bearing to a suitable height, set it in motion, record the time for 20 swings, and enter that time and the length of their pendulum in a Google form where the data entered by all users were aggregated and displayed on a graph driven by a Google sheet. The intention was to use the pooled data to estimate the gravitational constant which users were also invited to calculate directly for comparison with the pooled result.

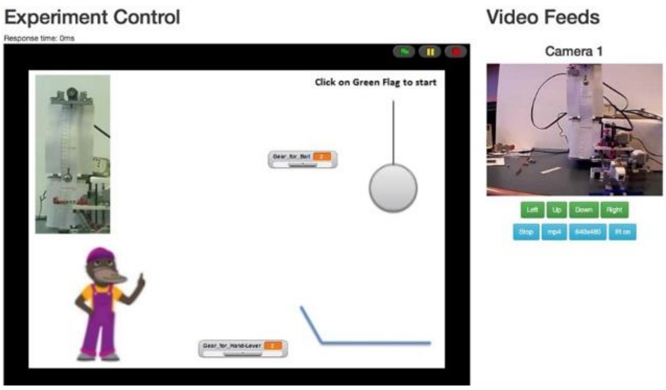

Figure 2. RALfie Pendulum activity

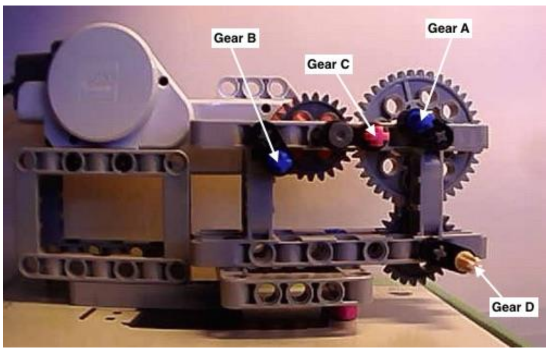

Figure 3. RALfie Gearbox activity

The Gearbox activity in Figure 3 presented users with a gearbox constructed using LEGO and the challenge to determine the ratios among the 4 gears, A to D. The setup included a graphical user interface similar to that shown in Figure 2 but omitted in Figure 3 to afford a clearer view of the gears. Users were able to remotely control the motor to rotate Gear C through a selected angle (in degrees) and observe and record the rotation of the other gears to determine the ratios.

Data collection and analysis

An online questionnaire using LimeSurvey (limesurvey.org) captured quantitative data about affective states, using PANAS (Watson, Clark, & Tellegen, 1988) before and after the RALfie intervention. The second questionnaire included open ended questions to gauge reactions to the experience. Quantitative data were extracted from LimeSurvey for analysis using SPSS. Scores for PA and NA were calculated for each participant on both the pre-test and post-test applications of PANAS. The differences between those scores for each participant were calculated to examine the changes in their PA and NA. From 168 enrolled students invited to respond, there were 122 completed questionnaires from the first administration and 47 from the second. The pre-post survey data (N = 40) were inconclusive because the numbers of respondents in different conditions were insufficient for statistical analysis. Subsequently the pre-post survey data were used to guide selection of interviewed participants for closer investigation as cases.

Qualitative data from the second questionnaire and transcribed interviews were imported into NVivo and analysed thematically to develop case themes. Semi-structured interviews were conducted with six PSTs using prompts based on the research questions. Participants were asked to recount their experience of working with hands-on and online RALfie activities and comment on which activities worked well for them and which did not and why. Participants were asked to comment on aspects of the experience that made them feel more or less confident to teach the Technologies Curriculum, and the support they need in the future.

Three overarching themes, each with sub-themes, were generated from the qualitative data. The overarching themes related to advantages of the RALfie activities experienced by participants, issues experienced while accessing RALfie activities, and effects of personal background on the experience.

This paper reports data for two PSTs for whom there were notable changes in affective states as measured by the PANAS. Each case starts with description of PANAS results, which is followed by a case description including elements of biography and reactions to the RALfie experiences (Meyers & Bagnall, 2015).

Case studies

Case 1. No. 28 Sally

Figure 4 presents a scatter plot of pre-test score (X-axis) against post-test score (Y-axis) for PA with the four groups of respondents identified as shown in the legend. Points above the diagonal line represent respondents who scored higher on the post-test than pre-test. Points below the diagonal line represent respondents who reported decreases in PA.

For the pre-post PA score, Sally was an outlier whose pre-post PA score difference was greatest among the six interviewees, indicating that Sally had a notably positive experience with RALfie. Her PA score increased from 1.50 to 3.20, and her NA score decreased from 1.70 to 1.20. The implication is that she was engaged during the RALfie experience and enjoyed it.

Sally was in her early 20s and was in the final year of her preparation to be a primary school teacher. She was an online student and participated only in the RALfie user activities, spending a total of 1.5 hours on them. The Pendulum activity did not work for her but the Gearbox activity did. She was willing to use RALfie to teach in the future and thought she could host an experiment herself for a class if she was provided with a RALfie kit. Five themes emerged during analysis of her data.

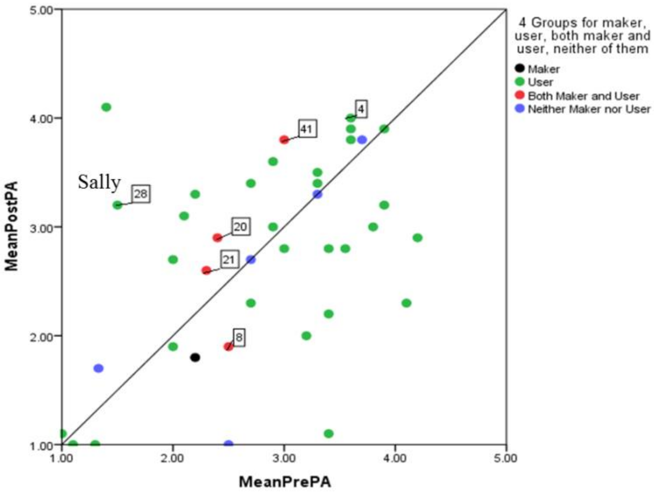

Figure 4. Pre-post comparisons of positive affect scores

Theme 1: Science learning experience in primary school

Sally had a very positive learning experience with science when she was a child. She commented that *"when I moved to Queensland the teacher I had in Queensland he was very positive toward, especially science and things and trying to make it interesting and very hands-on."*

Sally's positive science learning experience in primary school led her to continue to learn science at university and she stated that *"I know a couple of the science. I've actually used those experiments at Uni and I think it was in 1st year the science course. So that was another good one as well."*

Sally believed that her positive science learning experience during childhood helped her to become confident to teach science. She stated that *"I'm sure that really does just being confident in that area or having a good experience myself in that area especially with science in the classroom, quite positive to teach that one."*

Theme 2: Prior experience of LEGO

Sally had seen LEGO kits when she was in her teaching practice placements and commented that *"I'd actually seen that before on a previous prac that they used the little LEGO kits in the classroom and the kids…it could've been 2 to 3 times I've seen LEGO being used … I've had a positive use with it in the classroom."*

Theme 3: Hands-on experiences

Sally preferred participating hands-on with RALfie because the hands-on activities were concrete and playful. She explained that *"just being able to touch it and feel it and play with it would be a bit easier. Sometimes you've got to watch something a couple of times online to fully grasp what is being done or what is being said."*

Theme 4: The ease of use of online RALfie and resources

Sally had a positive experience going through RALfie brochures, RALfie websites, and YouTube Videos. She commented that the materials *"advertised it at the start on the brochure…I found it quite easy to get around and click on different things and have a look and the instructions… I found getting through the different activities and quests wasn't too bad and your website as well"*

Theme 5: Scaffolding by professional engineers and educators

Sally commented on the cooperation between the course lecturer and the RALfie team, stating that *"I think that was done really well especially with the quests and it was really easy to access from the course."*

Case 2: No. 20 Anissa

Figure 5 shows the pre-post comparisons of NA scores. PSTs who are located below the diagonal line experienced a decrease in NA between first and second administration of the PANAS, demonstrating a generally positive response to their experiences. PSTs located above the diagonal line recorded an increase in NA across the period of the study and may have experienced an increase in anxiety. For Anissa (No. 20), her pre-post NA increase was greatest among 6 interviewees which was a negative indicator. Her NA score increased from 1.40 to 2.00. The implication is that she experienced increased negative affect possibly including heightened anxiety during the RALfie experiences. However, her PA scores increased from 2.4 to 2.9 which suggests that RALfie experiences offered something enjoyable to her.

Anissa was in her early 20s and was in the final year of her preparation to be a primary school teacher. She participated in both maker events and the user activities. She had a positive experience with the maker events, spending a total of 3 hours across the two maker events. She experienced some difficulties with operation of the online user activities at both university and home and spent just 20 minutes attempting the online user activities.

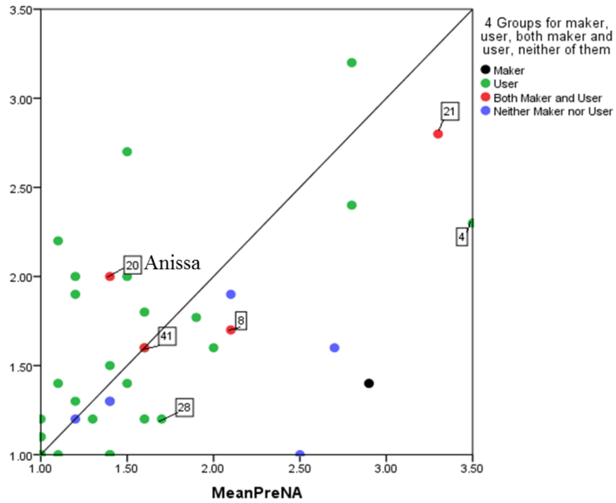

Figure 5. Pre-post comparisons of negative affect score

Theme 1: Science learning experience in primary school

Anissa did not enjoy learning science and technology when she was in primary school. When Anissa was asked why she was scared of learning science and technology, she commented that "*I just never have liked it at school. Like the perception was ruined for me I think – like the way they taught it and what was expected and stuff.*"

Anissa did not learn much science at primary school which made it hard for her to continue to learn science at high school. "*Well for primary school we hardly did any science so when I got to high school it was like you should have had all this knowledge which I didn't have because at my school science wasn't a big deal*."

Anissa further commented on the negative preconception of science learning, stating that "*I think there is a perception at school. Like science is like the smart subjects and like you can't do them at school – you're not going to be able to do them at university.*"

Anissa commented on her increased confidence as a science and technology teacher and stated that "*it's developing as I go further through my degree. If you'd asked me at the beginning I would have been scared to teach science and technology but now I'm getting more confident like knowing things.*" It was consistent with her low pre-post PA and high pre-post NA result.

Theme 2: Prior experience of LEGO

Anissa commented on her successful learning experience with Robot Soccer activities thus, "*I can do it; … I shouldn't be afraid of technology as much as I am. Like the making of it wasn't hard and once you got Scratch down – like it was quite easy.*"

After the RALfie experience, she was more likely to join in Robogals and teach robotics. Robogals was a robotics organization with a branch at University of Southern Queensland. Robogals use LEGO Mindstorms to program robotics and teach them at local primary and secondary schools. Anissa stated that "*I have been asked to join Robogals a couple of times but I didn't think I would be confident enough to do it…but probably now I would. Because from the RALfie like seeing it's not as hard as I thought it would be I think was my preconceptions that it was going to be really difficult but it wasn't so*."

Theme 3: Hands on experiences

Anissa liked the maker event "*Because I was engaged – like I had stuff to play with…the making one was more engaging – like seeing the whole process from start to finish*."

Anissa was more positive and willing to try new technologies after the experience of the RALfie maker event. She stated that "*Probably anything is possible. Like you don't have to be scared of it because it is like doable like it is attainable if you set your mind to it*."

Theme 4: Resources

For the user activities, Anissa enjoyed the Gearbox activities *"because you had to think – like the maths side of it comes into it as well. Like thinking about the degrees and if I turn that one then that one's going to turn that far and then it's going to go opposite and thinking about all the different aspects that come together just to turn one little thing was really interesting."*

Theme 5: The ease of use of online RALfie

Anissa gave up when the RALfie system did not work, stating that "*it wasn't working and there was a glitch with the computer so it wasn't working so I gave up pretty easily*."

Theme 6: Scaffolding provided by professional engineers and educators

The instructor's encouragement and scaffolding was important for engaging PSTs to try RALfie. Anissa commented that "*he really wanted us to learn Scratch and do the activities. Like there was always time set out to do it so we had the opportunity. If we couldn't do it at home we could always do it in class. Like he was always very encouraging that we at least try to do it."*

The course instructor taught PSTs how to use Scratch which helped them to use Snap!. "*I think if you didn't have a knowledge of Scratch and you were told to program something you would fail. Like just the little knowledge of Scratch that I had at the first Maker event – it helped immensely*."

Discussion

Based on the data presented above, it is suggested that the following factors make a difference in PSTs' experience of RAL: science learning experience in primary school, prior experience of LEGO, scaffolding by engineers and educators, access to resources, hands-on experiments, and the ease of use of the online RALfie system. The following sections discuss the results from the cross-case analysis with references to the related literature (Ebrahimi, Faghih, & Marandi, 2016).

Science learning experience in primary school

Sally and Anissa had contrasting science learning experiences in primary school. It is evident that Sally had a positive science learning experience in primary school. She commented that "*the teacher I had in Queensland, he was very positive toward science…and very hands-on.*" On the contrary, Anissa did not learn much of science in primary school, which contributed to her insufficient background knowledge for science learning at tertiary level. She stated that "*for primary school we hardly did any science so when I got to high school it was like you* *should have had all this knowledge which I didn't have*." This was consistent with the literature suggesting that the decrease in study of science at high school develops from lack of science learning in primary education (Westerlund et al., 2011).

Sally and Anissa demonstrated different attitudes towards science teaching because of their different science learning experiences in primary school. Sally stated that "*I'm sure that really does. Having a good experience myself in science in the classroom make it quite positive to teach*." Sally was very confident to teach science because she has a positive science learning experience. Anissa was scared of science due to her lack of science learning in her background. She commented that "*I just never have liked it at school.*" Prior experience and background knowledge are important to construct new knowledge (Vygotsky, 1978). Sally's positive learning experience of science in primary school led to her positive attitudes and confidence to teach science. Whereas for Anissa, lack of prior knowledge and background learning resulted in her negative attitudes and anxiety to teach science.

Prior experience of LEGO

Sally had a very positive experience with RALfie. Her prior successful experience of using LEGO to teach in her teaching practicum gave her a positive outlook to use the online RALfie activities. She knew that children will be excited about using LEGO to learn in the classroom. She was very confident to use the Gearbox activity. Anissa's lack of prior experience of using LEGO contributed to her anxiety. It is consistent with the literature that learners construct knowledge based on their prior experience and background (Vygotsky, 1978).

Scaffolding by engineers and educators

Scaffolding provided by the RALfie team supported PSTs to use the online RALfie activities. The course instructor taught them how to use the Scratch programming language before the maker events. Anissa adapted her background knowledge of programming to use the Snap! language, demonstrating it was easy for her to build on her prior knowledge and internalize new knowledge (Vygotsky, 1978). There were engineering academics who provided the RALfie system and also offered face-to-face interaction with PSTs in the maker events. Social interactions between PSTs and the engineers were important to create a supportive learning environment. The course instructor's encouragement also helped PSTs to alleviate their anxiety levels and to try new technology.

Resources

Resources provided by the RALfie project were important to engage PSTs. Brochures, websites and videos were used for demonstration which was very helpful to engage PSTs to use RALfie. Sally enjoyed watching the videos and navigating the RALfie website. Providing high quality resources was important to build up PSTs' confidence and capacity to teach (Albion & Spence, 2013). Resources are also important to PSTs' professional learning.

Hands-on experiences

Hands-on experiences provide a sense of playfulness which was helpful to alleviate the sense of anxiety and frustration with using robotics. Anissa stated "*I was engaged – like I had stuff to play with*," which was in line with her increased PA score. Hands-on activities are engaging as PSTs can tinker, play, and build things. Playing and tinkering with hands-on equipment was important for PSTs who were at the beginning level of using robotics. Moving from concrete maker activities to abstract user activities was in line with Piaget's learning stages theory (Piaget, 1974). It was also in line with the RALfie project's concept that "f stands for fun." Before the engagement with maker activities, Anissa was reluctant to join in the Robogals. However, after engagement with the maker activities, she was more willing to participate in the Robogals. Hands-on experiences were important to build up Anissa's confidence and capacity to use robotics. Moreover, hands-on experiments were powerful to engage learners to learn science for future career pathways (Westerlund et al., 2011).

The ease of use of online RALfie

The ease of use of online RALfie activities contributed to Sally's enjoyment and engagement during her interactions with RALfie experiences. Overall, Sally had a very positive experience with RALfie which is evident from her increased PA score and decreased NA score. However, Anissa experienced difficulties with using the online activities. Anissa stated that "*It wasn't working and there was a glitch with the computer so it wasn't working so I gave up pretty easily.*" Her increased NA score after her RALfie experience was consistent with experiencing anxiety while working with RALfie. The difficulties of use and unreliability of the online activities contributed to Annisa's anxiety and disengagement. Therefore, the ease of use of the online system affects PSTs' emotional status when using RALfie. It is important to make the online system user-friendly.

Conclusion

The cross-case analysis described above yielded useful insights into the areas probed by the research questions. RAlfie is a variant of RAL. Hence the user experiences and feedback on the technical problems and teacher support PSTs needed for RALfie are relevant to any consideration of more extensive use of RAL to support professional development of teachers or for direct use in primary school classrooms.

The most influential factor influencing PSTs' experience of RAL was their background knowledge and prior STEM experience in their own primary and secondary education. PSTs who had a positive experience with STEM learning in primary school were more likely to be positive and confident to use RAL. PSTs who had a negative experience with STEM learning in primary school were more inclined to hold a negative attitude and be anxious about using RAL. This highlights the importance of primary STEM education for prospective teachers' confidence and capacity to engage with STEM activities.

A second influential factor was direct access to the activities. Hands-on experiments were powerful to motivate and engage PSTs to learn robotics. For PSTs, especially for those who did not learn much science and technology in their own schooling, hands-on activities were playful and enjoyable which was helpful to alleviate their STEM anxiety. Compared to conventional RAL systems, the distributed feature of RALfie offers potential for users to take full advantage of RALfie as remote makers and users regardless of location.

The third factor that affected PSTs' responses to working with RAL was their user experience, which was influenced by the reliability of the systems and the levels of support available either directly or indirectly. Scaffolding was of great importance, both instructional scaffolding provided by professional engineers and educators in the laboratory or in the presentation of online activities and technical scaffolding to make the RALfie system reliable and user-friendly. The technical scaffolding was particularly important to alleviate PSTs' anxiety and increase their engagement.

Each of these factors affecting PSTs' experience of RAL points to lessons for the future application of RAL in primary education. PSTs' own experience of STEM influenced their willingness to engage in the activities. Hence, it seems logical that teachers with positive experiences of STEM will be more likely to engage with and offer STEM activities in their classrooms. Thus it is important to provide more STEM activities for primary school teachers and teacher candidates to boost their prior experience with STEM. RAL offers advantages for overcoming the challenges of distance in Australian education systems by making available a broader range of experiences than would otherwise be possible. Those experiences could be valuable for teacher professional development and for direct use with students in school classrooms.

Direct access to hands-on activities was especially motivating for the PSTs and the same is likely to apply for teachers and students in school classrooms. The distributed feature of RALfie offers particular advantages because it would allow schools to share experiments and to take full advantage of RALfie as remote makers and users. RALfie has the potential to provide hands-on and online opportunities for teachers to develop capability and confidence for implementing the *Australian Curriculum: Technologies* and to offer a wider range of learning opportunities for students in their classrooms.

Finally, user experience is an important factor to be considered in any system, especially one which is intended for use by children and inexperienced users. If RAL is to be used successfully to enhance the learning opportunities available to teachers and students in isolated schools, the system needs to be designed for ease of use and supported by adequate documentation and other supports.

This study, though small in scope, identified factors influencing PSTs' use of RAL and some implications of those findings for broader application of RAL for use by teachers and students in isolated schools. If those findings are heeded RAL, especially in the distributed format facilitated by RALfie, can make a valuable contribution to the development of teachers' capacities for implementing the *Australian Curriculum: Technologies* and to the resources available to support students' learning about technologies. By doing so it will enable Australians to create their preferred futures with greater opportunities for shared prosperity through application of STEM knowledge.

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