Qualitatively Different Ways Students Experience Remote Access Laboratories*

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This paper reports variations in students' experience of using remote access laboratories (RAL). Outcomes describe what students are actually attending to when engaged in RAL activities. The research was informed by the well-accepted and documented qualitative research method of phenomenography. Four qualitatively different conceptions are described, each revealing characteristics of increasingly complex student experiences. These conceptions reveal increasing awareness of certain aspects of RAL, the most notable of which is how the realness of the activity affects student engagement from simple experimentation to an appreciation that linking theory with practice provides a rich learning experience and can prepare them for professional work. The research outcomes inform pedagogy by providing a platform for improving RAL development and facilitation practices and thereby improving student learning outcomes.

Keywords: remote access laboratories; RAL; phenomenography; online learning

1. Introduction

1.1 Overview

The global context framing this research is one of strong international interest in, and converging standards of, pedagogy surrounding open-source educational materials. International interest is increasing in the content, nature and quality of open online courses, particularly at undergraduate university level. A key element of this type of learning is for students to have facilities to augment theoretical learning with practical application activities. In some cases this has been achieved by providing students with access to experimental laboratory activities through remote access laboratory (RAL) technology. Unlike simulations, RAL allows students to remotely control physical laboratory equipment and receive real data from experiments. Students may approach these RAL activities in different ways, leading to different quality learning experiences. Consequently, a phenomenographical study was carried out to investigate the qualitatively different ways that students experience RAL learning activities. The outcomes report qualitatively different experiences of remote laboratories in a higher education context, and are presented as categories of description and relationships between these. A key benefit of this research is an enhanced understanding of the critical ways in which students learn through the use of RAL, which will inform pedagogical practice.

1.2 Context and background

In recent times the latest technological innovations have facilitated the emergence of laboratory activities being conducted online through RAL to augment technical course content delivered online. Research in this area to date has largely focused on delivery platforms and technical issues rather than delving deeply into the student learning experience.

It is well accepted that an integral component of education for technology-based professions is the need to become familiar with tools and equipment relevant to the profession. Published research literature has long identified the need for hands-on practical instruction to supplement theoretical content so that students can integrate theories with practical reality [1]. This type of experiential learning was identified by Kolb [2] and described as using experimentation in a cycle of actions including concrete experience, observation and reflection, conceptualisation and testing. It is also consistent with Bergsteiner and Avery's [3] learning-activity types, particularly 'observe live activity' and 'engage in live activity'—the latter is most important, since RAL affords this authentic engagement albeit in a computer-mediated manner.

In most technology-based fields, particularly Engineering, physical laboratory equipment is generally quite expensive. Unfortunately this equipment is under-utilised in most higher education institutions. Recent ICT advances have supported the trend towards RALs where students can control and manipulate real physical laboratory equipment remotely through the internet or similar platforms. This leads to greater equipment utilisation as well as facilitating more flexibility and advanced knowledge co-creation through sharing, particularly when coupled with discussions facilitated through a learning management system or similar. It is worth

noting at this point that in the context of this paper RAL is referring to physical equipment, and not their virtual counterparts (such as might be found in Second Life for example), nor simulations, nor remote access to software applications.

As well as offering an opportunity to supplement content with real-time experiments using expensive and perhaps delicate laboratory equipment [4], offering RAL activities to online students has been shown to be effective in terms of achieving learning outcomes [5]. Though this is not universally accepted (for example see [4]), some authors suggest that RALs may even provide superior benefits compared to traditional hands-on laboratories due to: more time being available to access equipment; cost savings; greater range of activities (perhaps predicated on resource sharing); and moderation of safety issues [6]. Current debate, though, seems to have progressed past the value of RAL versus physical laboratory classes even though the results of this debate are not universally accepted. Regardless, much of the research used to 'demonstrate' equivalence and superiority is based on student perceptions 'discovered' from responses to surveys and only rarely augmented with results of reports or student reflections. This raises questions about the nature of these findings and how representative the reported perceptions are.

Further, recent scholarship and research on RAL, while proposing a significant rethinking of physical laboratories and intended outcomes, make no mention of the contribution of students' focal awareness or experience to help inform the pedagogical approach. Students' awareness and conceptions of their learning are central to the quality of their learning [7–9]. It is also recognised that students' focal awareness and conceptions are critical to learning in virtual communities [10]. Therefore an understanding of conceptions of how students experience RAL activities remains unknown and presents itself as an important area for focused research that is central to understanding the pedagogical design of RAL activities.

A key outcome from an ABET Colloquy in 2002, which was focused on educational aspects of Engineering laboratory classes, was a taxonomy of thirteen learning objectives that establish characteristics considered necessary for a positive laboratory experience [11–13]. Some researchers have used these ABET objectives for evaluating the efficacy of distance delivered engineering laboratory programmes. For example, using this framework, Lindsay and Good [14] demonstrated that students' engagement with physical laboratory equipment can be quite different to hardware that is physically separate from the student such as in another room, and that this difference can have a significant impact on the nature of their learning experience. This difference can be in terms of both learning outcomes and student perceptions. Lindsay [15] noted that students' changed perceptions of their learning environment and the way in which they engage with simulated laboratory experience through responses to surveys administered at the midway point and again at the end of a semester. In a similar study Lindsay et al. [16] reported results of a survey of students responding to questions on a ten point scale. In this latter study, to provide richer data and to try to capture students' reflection about their learning, students were also asked to respond to open questions. Although these open responses represented an advance in the research thinking, the design validity of the questions was not explained, and the analysis of the feedback seemed to be confined to a basic thematic analysis.

The questions are raised then: what are these differences in student experience; are they qualitatively different; and if so why? One element identified by Lindsay and Good [14] and Faltin et al. [17] was that remote access may lead to students questioning the reality of the experimental experience and it was concluded that the need to establish presence is of critical importance [18]. Presence suggests that students are aware of some elements that lead them to experience the RAL as believable and real. Discussing the use of virtual reality and augmented reality to support student learning, Santos et al. [19] identified that the interaction offered by these systems needs to feel as realistic as possible. They separated the students' perception of reality into two discrete concepts: immersion and presence. Immersion is concerned with how well the artificial stimuli such as sights, sounds and touch replicate the real world; and presence is concerned with the psychological sensation of actually being part of a particular environment. Presence then is related to how valid and consistent students' perceive the learning experience to be—essentially, how believable it is. An understanding of this awareness, regardless of whether or not students are consciously focusing on particular elements, is an important area of research.

Simply asking students to respond to pre-determined questions may not always yield expected outcomes. For example, students are not free to introduce new concepts and their thought patterns are influenced by the act of reading the questions. Some students may tell the researcher what they believe they want to hear rather than what they have experienced. Further, what students say about their experience may not align with their real learning outcomes. This was illustrated by Corter et al. [20], noting from correlation analysis of their findings, that students were possibly using their sense of

immersion to judge learning. Therefore student ratings on related questions alone could not reliably predict learning effectiveness. It is fair to say that early evaluation frameworks for RAL activities were largely based on student questionnaires and were somewhat superficial with a focus largely on student (and to some extent staff) satisfaction rather than complex learning outcomes [21] and pedagogical considerations. More advanced research is needed to move debate forward to investigate the relationship between learning outcomes and what students are attending to, and the general nature of the learning experience for students. Even more pressing is the need to carry out valid and reliable qualitative research to extend results from these earlier questionnaire-based studies, so further research in this fledgling field can progress on a solid foundation.

1.3 Aim

The aim of the research reported in this paper is to identify the qualitatively different ways in which students experience RAL. In this study we are interested in emphasising collective experience rather than the learning experience of any individual. The collective voice is important since it helps to surface the broader themes 'that—while not the true story of any one of us—at some level help to define the story of all of us' [22]. This aim will be pursued in the context of a higher education course that is supported by RAL activities. The RAL activities in this study will be restricted to hardware laboratories, and will not include simulations and software rigs. Nevertheless, findings probably will be transferable into these contexts and are therefore relevant to the current trend towards open-source courseware in all its various guises.

2. Methodology

The research was informed by the key theoretical constructs associated with the well-accepted and documented interpretative qualitative research approach of phenomenography. Phenomenography was chosen since it is concerned with the discovery of different ways in which people experience a phenomenon (such RAL) and is sympathetic to constructivism and transformational learning. Phenomenography is an ideal research method for this study since it focuses on the variation in students' collective experience, rather than their individual experience [7]. The primary outcome of the research is the constitution of a limited number of categories of description, including an explicit description of key qualitative similarities within, and differences between the categories and the

structural relationship between these categories [23].

The epistemological stance is based on an understanding that experience relates to the internal relationship between a person and the world around them [24, 25]. This is closely related to the post-modern understanding of knowledge as social construction, as opposed to the earlier modernist idea of knowledge being a mirror of reality [26]. However, social and individual constructivism usually adopts a dualist view where the self and the outer world are seen as separate. In contrast, phenomenography adopts a non-dualist stance where the outer world is not constructed internally by an individual, and nor is it imposed on an individual from the outside—rather it is considered that there is only one world that includes the individual and the 'real world' around them. This is described by Marton and Booth [7] as, 'There is only one world, but it is a world we experience, a world in which we live, a world that is ours.'

2.1 Context—the RAL activity

A suitable course offered at the University of Southern Queensland (USQ) was selected for this study. At USQ students may elect to study in the on-campus (internal) or off-campus (distance or external) modes. Approximately 75% of students study by distance education. USQ and professional accrediting bodies considers it essential that approximately 75% of students who are undertaking their studies by distance education are afforded an equivalent experience to on-campus students. In the Engineering programmes this is achieved through the practice course component of the programme. For example, students in the Bachelor of Engineering are required to complete 32 academic courses to meet the requirements of the course. In addition, they must complete around eight week-long practice courses (one week per equivalent semester of full time study) at various times during the course of their studies. These practice courses, which are conducted in residence on campus at USQ by all students, regardless of study mode, ensure that all students have adequate face-to-face access to professional practitioners, laboratory equipment and other practical activities. In some of these courses RAL is used to augment theory and used as prerequisite activity before students attend the residential schools on campus (for a good example, refer to [27]).

The practice course, ENV2902 (Hydraulics Practice), was selected for this study since students in this course use hardware-based RAL experiments. One of the RAL experiments involved using hydraulics equipment in the water laboratory. Students were required to perform some fundamental activities on
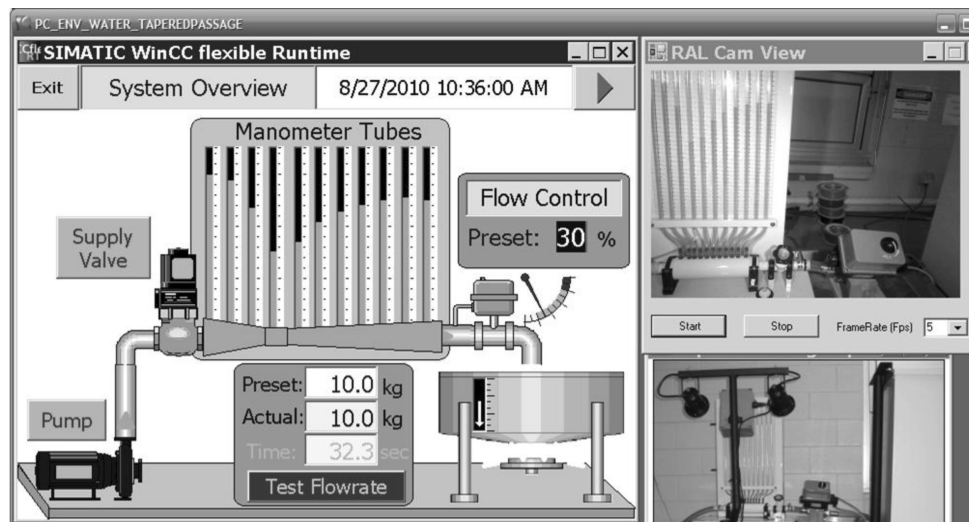
Fig. 1. Physical RAL experiment and digital interface.

this equipment before they could attend the on-campus practice course. The activities involved calibration of a ball valve and a link to the Bernoulli effect (see Fig. 1). This effect is observed in a pipe (a venturi meter) where fluid is passed through a constriction area and changes in pressure are observed in small tubes attached at right angles to the pipe. As part of this activity, students logged on to the RAL system, controlled the equipment, manipulated the Web cam, selected different pressure and flow settings, collected data, carried out calculations and graphed results. Detailed step-by-step instructions were provided to students on how to carry out the activities.

2.2 Participant profile

Students were recruited on a voluntary basis from those who attended the on-campus practice course, and had therefore recently completed the RAL activity. Eight students volunteered to participate in the research: three females and five males; one was under twenty, six were between twenty and thirty, and one was between 30 and 40 years of age; one was studying on-campus and seven were studying by distance mode. They were from a variety of backgrounds and across a range of past professional experience; their self-assessed expertise with information technology ranged from novice to experienced, and they were all Australian citizens. Although not large, it is considered that the participant base for the current study provided sufficient representation of students and their diversity for a broad range of categories of description to reveal themselves. While there is no prescriptive sample size for a phenomenographical study, enough participants are required to discern the variation in conceptions. Akerlind [28] provides recommenda-

tions on maximising sample variation (age, gender, experience and so on) with small sample sizes and provides readers an insight on a study she carried out with ten participants [28]. This sample size was therefore considered adequate.

At this point it is useful to acknowledge other potential limitations of the study. Data collection requires students to reflect on their own experiences of the RAL activity during an interview. Consequently, it is not possible to use a fully structured interview with an elaborate set of pre-determined questions. The phenomenographical approach requires the interviewer to adapt to the student being interviewed, and ask follow-up questions that are dependent on the student responses. This limits the data that is collected. Similarly, the data analysis is restricted to what is explicitly mentioned by the student in the interview, and this is considered by some to be a general limitation of phenomenography. Another potential limitation is that students' reflections will only relate to that specific point in time. It is conceivable that if the study were conducted again at another point in time, student responses would be different. Nevertheless the conceptions should not change significantly since these represent the collective voice of all students' responses. For this reason, although the sample size is low, it is important to include as much diversity as possible in order to reach stable conceptions.

Data were collected by semi-structured interview as described in the data collection section of this paper. Before the interview, students were fully informed of all relevant aspects of the proposed research project, both verbally and through the provision of an information sheet. All students were advised that the interview had no effect on

their grades in the course and the researcher did not have any connection with the course.

2.3 Data collection

An identical opening scenario was used for all individual student interviews asking students to reflect on their experience of using RAL activities in ENV2902 and describe it in detail. After the initial focus question, no further substantive input was made into the interviews by the researcher except to refer students to issues they had introduced, in order to get more complete explanations. In this way, only the students introduced new ideas and concepts. The researcher encouraged full disclosure from each student by various techniques such as asking for further explanation and reflection on elements mentioned by the students. Student responses were recorded and later transcribed into text for analysis of meaning.

2.4 Data analysis

The data analysis was guided by accepted practices surrounding phenomenography. Data analysis concentrated on developing a representation of the qualitative differences in students' interpretations of their experience of RAL. In accordance with the non-dualistic view characterised by phenomenography [24, 25], the students and their understanding of RAL were considered together during the data analysis. The responses as a group were analysed to map (discover) the limited number of categories of description that represent the main holistic meanings (qualitatively different ways of experiencing) that were revealed in the responses. The only evidence used in the development of the categories of description was that contained in the student responses.

A key outcome was the emergence of a series of categories of description, each representing one way

of experiencing RAL. The basic premise was that analysing students' responses would reveal a 'limited number of qualitatively different ways' [7, 29] of experiencing RAL, and that this would be possible even if the differences are grounded in reflective thought and not necessarily in immediate physical experience [7, 24, 25, 30]. The categories of description were explained and justified by representative quotations from the responses to exemplify the meanings. Later attention turned to determining if a logical organised structure existed that would represent the relationship between the emerging categories of description and this relationship then became part of the outcome space.

3. Results

3.1 Referential aspects

Findings are presented in four categories of description that represent the qualitatively different ways of experiencing RAL as expressed by the students who were interviewed. These categories of description and the relationship between them are summarised in the top section of Fig. 2. The arrows at the top of the figure represent the structural aspect of each category and the lower part of the figure represents a key dimension of variation: each will be addressed in some detail after discussion of the categories of description. Figure 2 represents the collective experience and the categories do not represent any individual student's perception. The aim was to capture the richness of experience, and consequently the final outcome space represents a collective interpretation that goes beyond any individual's experience of RAL. The categories of description reveal that RAL may be experienced as: Category 1—'Following the steps'; Category 2—'Playing around'; Category 3—'Theory put into

Categories of Description

Following the steps → Playing around → Theory put into practice → Preparation for the real world

Influenced by:
Instructions, Experimental Design, Context, Authenticity, Industry and Other Experience

Non-believer ----> Unsure ----> Believer

Dimension of Variation – Realness
Past experience and/or physically seeing RAL experiments – all believe after seeing
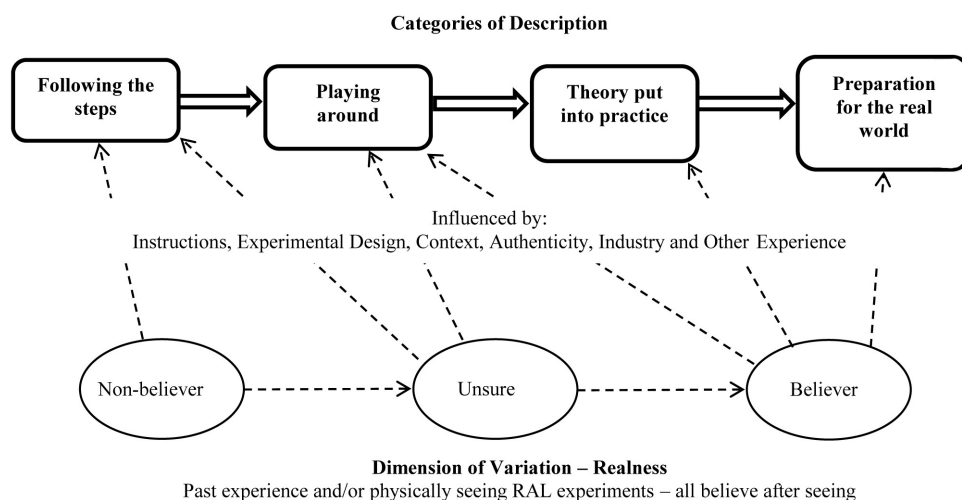
Fig. 2. Categories of description and dimensions of variation.

practice'; and Category 4—'Preparation for the real world'. These categories in order represent increasing awareness of certain aspects of RAL, demonstrating that the higher categories represent more complex and richer ways of experiencing them.

The qualitatively different ways of experiencing RAL are elaborated below in the meaning statement (referential aspects) of each category of description. The meaning of each category of description is supplemented with representative quotations from the transcripts to exemplify the meanings.

Category 1—Following the steps

In category one RAL is experienced as just following the steps to get the experiment done. When going about RAL in this way students' motivation is to follow the instructions provided to them simply to obtain some result that will be acceptable to the course administrators.

> I didn't really take a lot of time to look at all the information and really understand.
>
> . . . these are the measurements I need to take, and I need to do it quickly, so I just did it to get it done.

There is a view that the activity can be carried out simply by following the steps in the instruction guide and collecting the necessary data, without thinking about the results. This is clearly a surface approach to learning and there is no real engagement with the learning outcomes.

Category 2—Playing around

In category two RAL is experienced as an opportunity to experiment with the laboratory equipment. When going about RAL in this way the students' are interested in trying different variables beyond what was required to complete the designed activity. This is clearly a deeper approach to learning than category one, and indicates greater engagement with the learning activity.

> . . . log on to that experiment and sort of play around with it and see what figures I was getting and . . . really fully understanding what was actually going on.

Engagement expands to experimental learning and recognition that being able to conduct trials to see that happens is an aid to understanding the concepts. Some experimentation involved trying to break the system such as overflowing the recording bucket, and inputting variables too high or too low to see what would happen (and to see if safeguards were built into the system). Other experimentation indicated genuine trialling, such as seeing what output was achieved from different input values, and this 'makes it a lot easier to get a rounded understanding of the topic'.

Category 3—Theory put into practice

In category three RAL is experienced as an opportunity to put theory into practice. When going about RAL in this way students' main focus is on relating their theoretical understandings to practical outcomes from physical laboratory equipment.

> . . . basically theory put into practice, and if we'd had a chance to do that while we were learning just the theory for the whole semester it probably would have reinforced many ideas and concepts that we were trying to learn.
>
> I wish that I had it for every subject.

The engagement identified in category two has now expanded past simple experimentation to appreciation that linking theory with practice provides a richer learning experience, helps reinforce earlier understandings, and helps students to 'understand the concepts a lot better'. The practical nature of the activity aids understanding of the theory: 'seeing water actually flowing through a pipe' to obtain experimental values is an important adjunct to 'messing around with calculations'. There is also a consequential realisation that RAL should be included in all discipline-based courses, 'as an asset for us to use'. They also have a better understanding of how they learn: 'I am definitely a practical learner . . . I need to see things and get my hands dirty so to speak, to really fully understand a concept'.

Category 4—Preparation for the real world

In category four RAL is experienced as preparation for future work in the real world. When going about RAL in this way students' main focus is on how the activity relates to the workplace

> it is giving me an opportunity to learn about system structure before I actually have to use it in the real world.

There is awareness that this is just an introduction to what is expected in the professional work environment and this is important so 'it is not a totally foreign concept'. This represents an expansion past individual courses, through overall programme focus, and on to an application in professional life after graduation. Past experience seemed to be important in this category, which may indicate the importance of context in the design of RAL activities. Students not only realised that the water experiments were relevant to their future work, there was also appreciation that the design of the RAL system itself was relevant, 'I work in the water industry and they have water treatment plants and pump stations . . . all controlled via SCADA systems with digital interfaces . . . , and so by moving a lot of those experiments to a computer based digital inter-

face . . . it does prepare us a little bit better for what actually is out there in the field'.

3.2 Structural relationship

The arrows at the top of Fig. 2 linking the categories represent the structural aspect of the outcome space. The arrows depict increasing awareness of certain aspects of RAL from category one to category four in a linear relationship. The higher categories to the right represent more complex and richer ways of experiencing RAL and these contain elements of the lower categories.

3.3 Dimensions of variation

The lower part of Fig. 2 represents one critical aspect, realness, that is held in each category and that varies systematically across the categories. This is commonly referred to as a dimension of variation in phenomenographical studies. Realness refers to whether or not students believed the laboratory equipment was authentic as opposed to a simulation or replication. This is an important aspect since, as the dashed arrows in the middle of the figure show, this is ultimately related to how they experience RAL. For example, students who don't believe the experiment is using real equipment only seem to take a surface approach ('I just couldn't believe'). Experience of students who are undecided ('I had my doubts') on this aspect is restricted to the lower categories. Some students believe the equipment is real ('it was actually physical phenomena that we were recording'), though there was no evidence of this in category 1. Nevertheless, this belief in the reality of the equipment does not necessarily mean they will experience RAL in the deepest ways. This all depends on quite a number of factors. These factors include: quality of the activity instructions; how the experiment is designed; what context is used to frame the experiment; elements that aid authenticity such as Web cams and sound; students' past industry and related experience. Therefore, realness seems to be a necessary, but not sufficient, condition of experiencing RAL in deeper ways.

4. Discussion

4.1 Referential aspects

Conception 1, Following the Steps, is no surprise since this is similar to other studies, for example, a study by Gibbings et al. [31] into problem-based learning in virtual space revealed a conception, 'A necessary evil for course progression'. Students should be discouraged from taking this path of least resistance.

Conception 2 sees the emergence of experimental learning, which is similar to earlier discussions of Kolb's [2] cycle of actions: concrete experience, observation and reflection, conceptualisation, and testing.

Conception 3 has two distinct features, though the differences are not considered significant enough to warrant separate categories. One feature is the recognition of the general value of learning theory at the same time as practice, and the other related feature is recognition of the value in expanding RAL to other courses in their programmes. The first is consistent with the findings of Lindsay and Good [14] who noted the remote mode allowed students to focus on using the laboratory (RAL) to reinforce theory.

Category 4 relates to application in a real-world setting rather than just understanding. This is similar to the difference between seeking meaning and reproducing as noted by Marton et al. [32] and used for comparison and contrast by Gibbings et al. [31].

There is evidence of the expanding of students' external horizons from just getting the job done in category one, to thoughts of experimentation and what else may be learnt from the RAL equipment in category two, to wider thoughts on expanding beyond this course to the rest of their programmes in category three, and finally to professional work after graduation in category four. This expansion through the four categories can be paralleled to some extent with the Piagetian inspired SOLO Taxonomy [33], dealing with different ways of handling the same task. To illustrate this (although somewhat loose) alignment, Table 1 lists the categories from the present study on the left and matches these with the SOLO taxonomy on the right—suitable explanations are added for clarity.

RAL provides a vehicle for external students to gain contextualised declarative knowledge and at the same time concentrate on procedural knowledge, which was recognised as important by Poikela and Poikela [34] in the problem-based learning environment. To take advantage of this, what is required in association with RAL experiments are: framing experiments in contexts that make the link to authentic professional work; and activities to encourage self-reflection by students. Abrandt Dahlgren et al. [35] noted the importance of students making this personal connection with their future professional life. At USQ this integration will often be into students' existing work environments since external students are already working in some professional capacity. Regardless, simply making students aware of these different ways of experiencing the learning by designing appropriate activities in context may help usher them into deeper ways of experiencing RAL.

Table 1. Categories of description related to SOLO taxonomy

Conception 1 'Following the steps'. This surface approach shows no real engagement with the activity or the learning outcomes and consequently no crucial aspects of the task are mastered.	**Prestructural** The learner is distracted or misled by an irrelevant aspect, which leads to no crucial aspects of the task being mastered.
Conception 2 'Playing around'. This deeper approach to learning indicates greater engagement with the learning activity, including conducting trials to see that happens in order to assist understanding the concepts. Since the analysis do not make any distinction on the number of critical aspects, this Conception is linked to two items from the SOLO taxonomy.	**Unistructural** The learner focuses on the relevant domain and identifies one part to work with, which leads to one crucial aspect of the task being mastered. **Multistructural** The learner focuses on the relevant domain and identifies more than one relevant part but does not integrate them, which leads to several crucial aspects of the task being mastered but not integrated.
Conception 3 'Theory put into practice'. The main focus is on relating theoretical understandings to practical outcomes from physical laboratory equipment and the realisation that RAL should be included in all discipline-based courses. This linking of theory with practice is evidence of the integration and linking of several different critical aspects.	**Relational** The learner now integrates and relates the several crucial aspects with each other so that the whole has a coherent structure and meaning.
Conception 4 'Preparation for the real world'. The focus on how the activity relates to the workplace, and appreciation of the activity design, represent an expansion on earlier conceptions to application in professional life after graduation. This could be considered a generalisation and certainly involves some of the more abstract learning outcomes from RAL.	**Extended** The learner now generalises the structure to take in new and more abstract features. This represents a further expansion on Relational level to a new higher mode of conceptualisation.

4.2 Structural aspects

Students' belief in the realness of the RAL equipment seems to be related to two key factors: whether or not they have physically seen the equipment; and their past experience with similar equipment (usually in a work environment). All students indicated that they were believers after they had seen the physical equipment. An important deduction is that it may be beneficial to expose students, even briefly, to all RAL activities while they are on campus for the practice courses. In this way they may remember seeing the equipment and activities they will use in later stages of their programme.

The sense of reality or social presence was identified and discussed at length by Lindsay et al. [18]. Of relevance to the present research is their conclusion that it was possible to establish this sense of reality through 'immediacy behaviours' [18], though their suggestions were largely based on instructor behaviours, such as punctuality and vocabulary. Nevertheless, they concluded that an enhanced social presence would have a positive impact on student outcomes and 'higher affective and cognitive achievements' [18].

The dashed arrows at the bottom of Fig. 2 indicate that it is possible to influence students' perception of the realness of the RAL from non-believer through to believer ('at first I did think it was just a simulation, but then I started using it and seeing that it was actually physical phenomena that we were recording'). Providing students with an opportunity to physically see the equipment is one way to achieve this ('we didn't think it was live, until

we came to the course and saw it there') but another way may be to create this sense of reality online through the judicious use of Web cams and good quality sound ('you had your illustration, sort of, and then you had your Web cam and they were identical'; 'I can just still remember that little sound of that valve slowing turning and the pump coming on'). Zimin et al. report the use of multimedia audio-visual technologies to observe the experiment, and this may well be an area that warrants further research [36]. Of course, students would need a sufficient quality of internet connection for this to be effective. Simply changing this one element may affect believability and presence, and help usher students into higher ways of experiencing RAL.

Triggering students appreciation that the experiment is related to work in their chosen profession may be complicated. Although the context of the experiment is important, other extra-curricular factors such as previous work experience and related social interactions [37], which are outside the control of the designers of RAL activities, also play a significant role. In addition students need to understand the learning mechanisms involved, since this type of self-awareness is important for them to master the integration of theory with practice [38]. Providing the appropriate context, learning activities and environment are all important elements, but they may be insufficient by themselves to foster deeper ways of experiencing RAL. This may require clarification of the various ways of experiencing as well as astute self-awareness on the part of the students.

5. Conclusion

Results of this research reinforce findings of Lindsay and Good [14] with reference to the general value of learning theory and practice at the same time. This paper expands this notion by providing insights into students' awareness of the value of embedding RAL activities in other courses, as well as identifying potential benefits in their later professional careers. This research has highlighted the importance of framing RAL experiments in authentic professional work-related contexts. But, providing the appropriate context, learning activities and environment alone may be not sufficient to foster deeper ways of experiencing RAL—students also need to be made aware of critical aspects of their own learning. Consequently, by making students aware of different ways of experiencing these contextualised RAL activities, educators may usher them into deeper ways of experiencing RAL and thereby enhance their learning. Results also indicate that it is possible to influence students' perception of the realness of the RAL activities, and that this could have a profound impact on the believability and presence aspects of the activities.

Implications of the findings of this research for RAL designers are as follows.

- Take steps to ensure students appreciate that they are using real equipment.
- Make students aware of the various qualitatively different ways they may go about the RAL activity and usher them into deeper approaches.
- Encourage experimentation beyond the structured activities (semi-structured discussions and the formation of learning communities may help with this element).
- Make clear links to theory.
- Design activities in authentic contexts and explicitly make links to professional work after graduation.

This paper has reported the discovery of qualitatively different ways in which students experience RAL. This research has provided a platform for improving RAL development and facilitation practices as education providers seek to position themselves within emerging technology frameworks. Outcomes will advance and strengthen existing theoretical knowledge about RALs and provide a foundation for developing new and innovative methodologies for design and delivery of this type of instruction. Armed with this understanding of the critical ways that students experience RAL, curriculum design can be enhanced to support this learning and to usher students into more sophisticated ways of learning.

References

1. S. Kang, Y. Chan, C. Lu, J. Lai and T. Lee, Development of virtual equipment: case study of the venturi tube experiment, *Journal of Professional Issues in Engineering Education and Practice*, **139**(4), 2013, pp. 281–289.
2. D. A. Kolb, *Experimental Learning: Experience as the Source of Learning and Development*, 1984, Prentice-Hall, Englewood-Cliffs:.
3. H. Bergsteiner and G. C. Avery, The twin-cycle experiential learning model: reconceptualising Kolb's theory, *Studies in Continuing Education*, 2014, pp. 1–18.
4. O. H. Graven and D. A. H. Samuelsen, Remote laboratories with automated support for learning, *Remote Engineering and Virtual Instrumentation (REV), 2012 9th International Conference*, 2012.
5. R. Vuthaluru, E. Lindsay, N. Maynard, G. Ingram, M. Tadé, M. Ang and H. Vuthaluru, Use of digital technologies in bridging the gap between face-to-face and remote engineering programs, *Remote Engineering and Virtual Instrumentation (REV), 2012 9th International Conference*, 2012.
6. S. K. Esche, Remote experimentation—one building block in online engineering education, *2002 ASEE/SEFI/TUB International Colloquium on Global Changes in Engineering Education*, 2002, Berlin, Germany.
7. F. Marton and S. Booth, *Learning and Awareness*, in R. J. Sternberg (Ed.), The Educational Psychology Series, 1997, Lawrence Erlbaum Associates, Mahwah, New Jersey.
8. M. Prosserand and K. Trigwell, *Understanding Learning and Teaching: The Experience in Higher Education*, 1999, Open University Press, Buckingham.
9. P. Ramsden, *Learning to Teach in Higher Education*, 2nd edn, 2003, Routledge Falmer, London.
10. P. D. Gibbings and L. M. Brodie, The importance of focal awareness to learning in virtual communities, H. Li (Ed.), *Virtual Community Participation and Motivation: Cross-Disciplinary Theories*, 2012, Information Science Reference (an imprint of IGI Global), Hershey, PA, USA.
11. L. Feisel, G. D. Peterson, O. Arnas, L. Carter, A. Rosa and W. Worek, Learning objectives for engineering education laboratories, *Frontiers in Education, 2002, FIE 2002, 32nd Annual*, 2002.
12. L. D. Feisel and A. J. Rosa, The role of the laboratory in undergraduate engineering education, *Journal of Engineering Education*, **94**(1), 2005, pp. 121–130.
13. D. Lowe, G. Bharathy, B. Stumpers and H. Yeung, Laboratory lesson plans: opportunities created by remote laboratories, in *Remote Engineering and Virtual Instrumentation (REV), 2012 9th International Conference*. 2012.
14. E. D. Lindsay and M. C. Good, Effects of laboratory access modes upon learning outcomes, *IEEE Transactions on Education*, **48**(4), 2005, pp. 619–631.
15. E. Lindsay, Students' impressions of a hybrid real and simulation laboratory, *Engineering Education Conference*, 2006, Liverpool, England.
16. E. Lindsay, D. Liu, S. Murray and D. Lowe, Remote laboratories in engineering education: trends in students' perceptions, *AaeE Conference*, 2007, Melbourne, Australia.
17. N. Faltin, A. Bohne and B. Wagner, Evaluation of reduced perception and tele-tutorial support in remote automation technology laboratories, *International Conference on Engineering Education and Research 'Progress Through Partnership'*, 2004, Olomouc and Bouzov Castle, Czech Republic.
18. E. Lindsay, S. Naidu and M. Good, A different kind of difference: Theoretical implications of using technology to overcome separation in remote laboratories, *International Journal of Engineering Education*, **23**(4), 2007, pp. 772–779.
19. L. Santos, P. Escudeiro and C. V. de Carvalho, Evaluating virtual experiential learning in engineering, *2013 International Conference on Interactive Collaborative Learning (ICL)*, 2013.
20. J. E. Corter, S. K. Esche, C. Chassapis, J. Ma and J.V. Nickerson, Process and learning outcomes from remotely-operated, simulated, and hands-on student laboratories, *Computers & Education*, **57**, 2011, pp. 2054–2067.

21. D. Lowe, S. Murray, D. Liu, E. Lindsay and C. Bright, *Literature Review: Remotely Accessible Laboratories— Enhancing Learning Outcomes*, 2007, Australian Learning & Teaching Council.
22. N. Cherry, Phenomenography as seen by an action researcher, *Doing Developmental Phenomenography*, J. Bowden and P. Green (Eds.), 2005, RMIT University Press, Melbourne, pp. 56–62.
23. G. S. Akerlind, Principles and practice in phenomenographic research, *International Symposium on Current Issues in Phenomenography*, 2002, Canberra, Australia.
24. F. Marton and M.-F. Pang, Two faces of variation, *8th European Conference for Learning and Instruction*, 1999, Goteborg University, Goteborg, Sewden.
25. M.-F. Pang, Two faces of variation: on continuity in the phenomenographic movement, *International Symposium on Current Issues in Phenomenography*, 2002. Canberra, Australia.
26. S. Kvale, The social construction of validity, *Qualitative Inquiry*, **1**(1), 1995, pp. 19–40.
27. K. Dickmann and A. A. Kist. Remote networking laboratory development, *2014 11th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, 2014.
28. G. S. Akerlind, Learning about phenomenography: interviewing, data analysis and the qualitative research paradigm, *Doing Developmental Phenomenography*, J. Bowden and P. Green (Eds.), 2005, RMIT University Press, Melbourne, pp. 63–73.
29. F. Marton, Phenomenography—a reserch approach to investigating different understandings of reality, *Journal of Thought*, **21**(3), 1984, pp. 28–49.
30. A. Barnard and R. Gerber, Understanding technology in contemporary surgical nursing: a phenomenographic examination, *Nursing Inquiry*, **6**(3), 1999, pp. 157–166.
31. P. D. Gibbings, C. Bruce and J. Lidstone, *Problem-Based Learning (PBL) in Virtual Space: Developing Experiences for Professional Development*, 2009, VDM Verlag Dr Muller Aktiengesellschaft & Co KG, Saarbrucken, Germany:
32. F. Marton, G. Dall'Alba and E. Beaty, Conceptions of learning, *International Journal of Educational Research*, **19**(3), 1993, pp. 277–300.
33. J. B. Biggs and K. F. Collis, *Evaluating the Quality of Learning: The SOLO Taxonomy (Structure of the Observed Learning Outcome)*, 1982, Academic Press (A Subsidiary of Harcourt Brace Jovanovich, Publishers), Sydney.
34. E. Poikela and S. Poikela, The strategic points of problem-based learning—organising curricula and assessment, *PBL in Context—Bridging Work and Education*, E. Poikela and S. Poikela Eds), 2005, Tampere University Press, Tampere, Finland, pp. 7–23.
35. M. Abrandt Dahlgren, H. Hult, L. O. Dahlgren, H. Hard af Segerstad and K. Johansson, From senior student to novice worker: learning trajectories in political science, psychology and mechanical engineering, *Studies in Higher Education*, **31**(5), 2006, pp. 569–586.
36. A. M. Zimin, S. V. Korshunov, A. V. Shumov and V. I. Troynov, Remote access laboratories for training of engineers in the 21th century, *2013 8th International Forum on Strategic Technology (IFOST)*, 2013.
37. J. Walther, N. Kellam, N. Sochacka and D. Radcliffe, Engineering competence? An interpretive investigation of engineering students' professional formation, *Journal of Engineering Education*, **100**(4), 2011, pp. 703–740.
38. M. Q. Patton, What brain sciences reveal about integrating theory and practice, *The American Journal of Evaluation*, 2013.

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