Lockdown – practical science is virtually ~~im~~possible.

The virtual science laboratory in Further Education.

Abstract

Virtual laboratories (VL) have existed for a number of years and recently have increased in sophistication. These computer-based simulations can be quite simple or a highly detailed representations of a real laboratory. This work focuses on the use of VL in a Further Education College. The recent COVID-19 crisis has led to closure of the College, meaning that virtual laboratories are now the only ones available to our students.

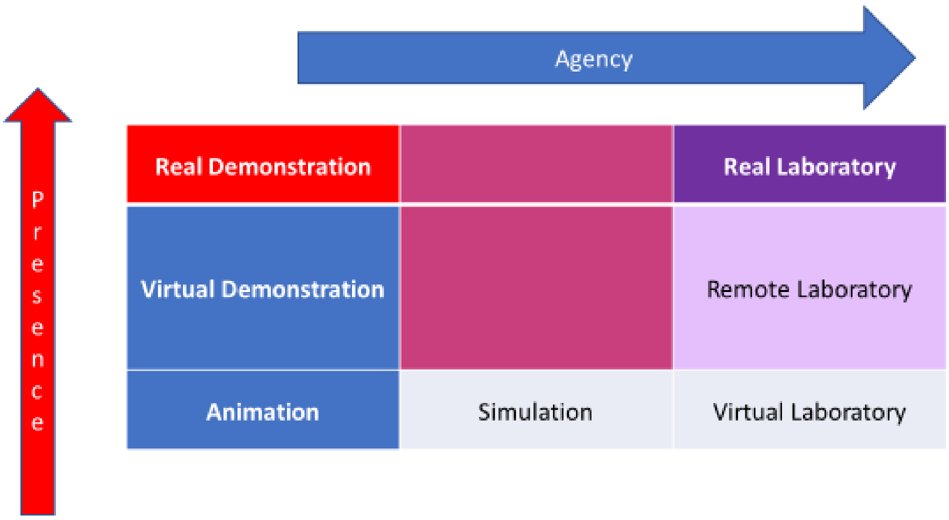
This limited study has suggested that there are a number of factors which affect how students view learning in a VL. When answering five questions about their learning in VL on a Likert scale there was a significant preference for real laboratories. Textual answers to accompanying questions suggested students can be excited and motivated by new technology, but difficult to use technology or software cause issues. Unlike many university students, Further Education students may lack the physical, academic and emotional resources or resilience needed to make the most of the new opportunities. Students' language abilities may inhibit access to new ways of doing things. Also, some students value the physical laboratory "because sometimes we need the teacher": this need should be considered when implementing virtual applications for Further Education students.

Introduction

In the "new world" that a global pandemic is beginning to shape, it is very likely that we will rely much more on digital technologies. Viewed from within the event (August, 2020) gives a perspective which tends to focus on the immediate. However, plans are being developed for an uncertain way forward. Education is an area where there has been, over the recent past, a move towards a more digitally based delivery of the curriculum (JISC, 2015). One strand of this digital development has been the emergence of the 'virtual science laboratory'; this has been particularly true in the context of higher education (HE) (Lewis, 2014).

Virtual laboratories (VL) have existed for a number of years and recently have increased in sophistication. These computer-based simulations can be quite simple or a highly detailed representations of a real laboratory. Some of the newest versions are based in virtual reality, providing an even closer feel of the real laboratory (RL). There are a range of different types of VL categories, this is expressed as a diagram of student engagement in terms of presence and agency in Figure 1. By presence, I mean how closely the student is involved - how visceral the interaction. While by agency, I mean the ability of the student to influence events.

Figure 1 Showing the variation in presence and agency for different environments.



Virtual laboratories offer a good way for students to develop practical skills; Miller, Carver and Roy (2018) found no difference in outcomes compared to real laboratories. So, it would seem reasonable to use them in a Further Education (FE) setting, the focus of this work. FE does present some particular challenges compared to HE, including funding, limited facilities, student motivation and prior attainment (DoE, 2018). However, the recent COVID-19 related closure of the College, means that virtual laboratories are now the only ones available to our students.

I would like to address the question “How useful to education are virtual laboratories?”. This raises number of issues: what is useful (skills, knowledge etc.); what is education? is further education different? who are the students? what is the learning context? who are the teachers? what are virtual laboratories? how are they different to real laboratories?

Following a short literature review, I introduce the aim, ethical considerations and methodology of the student survey. The results are then presented and some of the important themes which emerge discussed. Finally, some recommendations about future implementation of VL made.

Literature

The limited literature review is divided into four parts: the practical in science; VL in education; VL related to the scientific method and practical application of VL.

There is a considerable body of literature concerning the importance of practical studies in science (Dillon, 2008; Holman, 2017). I have decided to use the list given by Holman (2017) as the basis for the study, shown in Table 1.

Table 1 showing the main benefits of practical science, taken form Holman (2017).

1	to teach the principles of scientific inquiry.
2	to improve understanding of theory through practical experience.
3	to teach specific practical skills, such as measurement and observation, that may be useful in future study or employment.
4	to motivate and engage students.
5	to develop higher level skills and attributes such as communication, teamwork and perseverance

Holman's aims are part of the broader understanding of the nature of science and what constitutes the scientific education. Gregson and Hillier (2015) identify the main educational perspectives as behaviourist, cognitive and multidisciplinary: I will briefly review VL in the light of these.

The behaviourists view is that experiments are performed in a structured way to demonstrate predetermined outcomes. Students learn by observing the outcomes of the experiments, repetition helps with the reinforcement of learning. For the behaviourist the VL is ideal with predictable methodologies, results and rewards, as well as, the opportunity for multiple repetition. The "black box of the students' minds" (Gregson and Hillier, 2015, p.41), mirroring the black box of the VL; the focus is on input leading to output.

The cognitive perspective has more questions to ask of the VL. The mind is central here and how understanding is developed over time. For example, Ausubel's work (Gregson and Hillier, 2015 p.42) on meaningful learning requires students to reorder their cognitive structures; while the SOLO taxonomy of Biggs and Tang (2011), points to the need to include higher level activities. Many VL focus on the development of practical rather than cognitive skills.

The multidisciplinary approach draws on a number of fields of study, with several theoretical frameworks. Kolbe's concept of experiential learning (Gregson and Hillier, 2015 p.47) can be accommodated within a VL, which provides a concrete experience, from which observations can be made. Similarly, the idea of situated learning within the VL can be enhanced by the use of 'game' type scenarios. For social constructivism (Gregson and Hillier, 2015 p.48-50), the main issue is the potential lack of social interaction with most VL configurations. Although, VL embodiments can test learning throughout a planned scenario, there is no real opportunity to socially interact in most VL programs, nor are there opportunities for teamwork. Although some VL can provide scaffolded activities, there is little opportunity for individualisation of these. This is an issue if we wish to work in the zone of proximal development (Gregson and Hillier, 2015 p.49), as this is difficult to define using current software.

I want now to consider how the VL fits into the idea of ‘science’. The nature and practice of science has been developed over many centuries (Redman, 1993; van Ripper, 2020). Currently, in education, the prevailing paradigm is based around the scientific method (STEM, 2020) and the importance of evidence (Holman, 2017). How science develops over time has been a contested issue with conflicting ideas from thinkers such as Polanyi, Kuhn and Popper (Redman, 1993). These theories are relevant to the use of a virtual laboratory which is ‘fixed in time’. In a real laboratory there is genuine uncertainty due to procedure, physical conditions, variation in materials and the fundamental uncertainty of nature (Woods and Baumgartner, 2020), that means there cannot be absolute certainty of the result. A VL is fundamentally different, in that, the result is mathematically predictable, as it is based on a computer program and therefore on a numerically expressed model. Conceptionally, this causes a problem about whether the experiments carried out in a virtual laboratory are *scientific.* Polanyi claims “that the propositions embodied in natural science are not …verified nor falsified by experience according to any definite rule” but “relies in every case on a personal judgement exercised (or accredited) by ourselves.” He is therefore suggesting that the nature of science is contained in the tacit knowledge of the scientist. Redman (1993) states ‘The thrust of Polanyi's argument is that science does not rest on any purely objective method but is "a system of beliefs to which we are committed"’. Similarly, Sennett (2008) considers the “complicated repertoire” (p.50) of procedures which are developed by medical staff, leading to the “embedding” of skills and “the hands-on transmission of knowledge from generation to generation” (p.57) of craftsmen. Does the VL enables the creation of the scientist through the generation of the tacit understanding and knowledge? Sennett (p 41), quoting Weisskopf comments about computerised experiments, cautions that “When you show me the result, the computer understands the answer, but I don’t think you understand the answer”. Sennett talks of the “craftsman, engaged in a continual dialogue with materials” (p.125), something which is not possible in the disembodied virtual laboratory.

If we now look at the perspective offered by Kuhn, that knowledge is gained "by doing science rather than by acquiring rules for doing it" (Kuhn, 1970c, p. 191, quoted in Redman 1993, p. 18). Kuhn maintains that developments in science occur through revolutions, "an older paradigm is replaced in whole or in part by an incompatible new one" (Kuhn, 1970c, p. 92; quoted in Redman 1993, p18). Kuhn refers to periods of "normal science", between the revolutions, during such the “scientific community refine the disciplinary matrix” (Redman 1993). For Kuhn then the VL must be located in such ‘normal times’, as the paradigm is fixed by the algorithms used and new science is not possible.

Popper (quoted in Redman 1993, p.31) maintains that for science “*there is no induction*: we never argue from facts to theories, unless byway of refutation or "falsification."” This causes a problem when we consider the VL, here induction is key, with theory and observation tightly linked and no possibility of falsification. So, Popper might well argue that the VL is “unscientific”.

There have been a large number of studies of the application of VL these have mainly been focused on HE; for example, reviews by Brinson (2015), Heradio (2016), Potkonjak et al. (2016); Lewis (2014); Miller, Carver and Roy (2018); Wang et al. (2014). There are a large number of VL available: some free (see ChemCollective (2020), MERLOT (2020), MSU (2020), PhET (2020), RSC (2020)) and some commercial (Labster, 2020; Beyond Labz, 2020; PraxiLabs ,2020; VPLAB, 2020; FlashyScience, 2020).

Studies of 16-17 year olds appear limited, however, Rajendran et al. (2010) found a positive interaction for learners in India.

Theoretical analyses, such as that by Christopoulos and Pellas (2020) provide frameworks which will aid the implementation of VL.

Ethical Statement

The study is carried out in line with the latest BERA (2018) guidelines.

All participants give informed consent [BERA (2018) 8] and are informed of their right to withdraw [BERA (2018) 31]. The document in Appendix 2, was given to each participant. Care is taken that no harm or disadvantage results from the participation in this study [BERA (2018) 34, 35, 36] any disclosure will be treated in accordance with The Sheffield College (2019) safeguarding policies.

Data will be collected and stored in accordance with BERA guidelines publication [BERA (2018) 48-50] and GDPR (2018) regulations. The results of the study are disseminated by publication [BERA (2018) 72] with care to anonymise the identity of the participants [BERA (2018) 40].

Although this research is funded by the Education and Training Foundation (ETF), the Foundation does not influence the conduct of the research or its outcomes.

Method

I started this project with a large number of questions. These I have refined down to three general questions:

Does teaching practical science in a VL increase students' skills and understanding in the same way?

How do our students feel about their learning?

Will our students develop the employability skills required by employers?

These are still too extensive and vague for a limited study. I decided to use the five outcomes identified by Holman (2017) as a basis for questions about how effective the students found VL compared to RL. I designed an online questionnaire with two questions about each outcome, the first, on a five-point Likert Scale and the second, a more open question, inviting a text answer; an example is shown in Appendix 1. Both questions address the comparison of experiments carried out in RL with those in VL, the results are recorded in Appendix 3. A further, more open questionnaire was given to some students later in the study, the replies recorded in Appendix 4, form the basis of the 'In the laboratories' section.

The questionnaires are presented as additional tasks after the completion of a VL similar to a RL which had been undertaken earlier. This is not ideal and may bias the results; however, qualitatively, we can hope to gain some useful insights. Following the work of van Maanen (see Connelly and Clandinin, 1990) I concentrate on the verisimilitude of the comments rather than their strict validity. Due to the College closure this is the best option available.

This study concerned students at a large midlands Further Education (FE) college, studying level 2 and 3, BTEC Applied Science programmes. Following science courses, our students are familiar with the "normal" school or college science laboratory. These students come with a wide range of experience; the majority coming from ethnic minority backgrounds, many are non-native English speakers. Often, they have previously been disappointed by low levels of attainment. Many lack self-confidence and resilience when faced with new challenges.

In the laboratories

Students carrying strange objects, moving around the room like birds gathering nesting materials. Groups of two or three students huddled round these objects, prodding, fussing building contorted loops with wires or nursing small beakers of coloured crystals. Each participant dressed alike – robed in white, eyes covered with ill-fitting safety glasses.

Noise, chatter, as students test each configuration of the unfamiliar equipment against their written plan. How are these connected? What does this do? We need another one of these.

Sometimes, heat and an unsettling shifting light from the yellow glowing gas swaying above the Bunsen Burner. Hair tied back for safety.

A smell, sometimes acidic or acrid or sweet but always a 'chemical smell'.

Fingering, touching, cold metal, warm glass, rough – smooth – rough, unexpected textures.

The science laboratory in a Further Education College is an "exciting" place, rich in stimulation for the senses; it can energise and lift students "more fun", "you can do the experiments hands on". There is a buzz to the lab where you "can work in teams" and "actually see what's going on". "Dealing with real chemicals and equipment" and if you are unsure, you can always "communicate with people around me and the teacher which helps". There in front of you, you "see real, not hypothetical results"; a visceral experience in which you are present. The story from most students is "I really like doing experiments and I love being in lab".

Yet the lab can be a scary place, for some become "nervous and panicked", they find the place overwhelming.

Serene, paced, in control, time to think, quiet work in a virtual laboratory space. Only you to make the decisions decide on the best course reflect on progress. "Rewatch", "take my time and complete the work as fast or as slow as I want", a gentle shift "back and forth" to settle, to learn. The virtual laboratory seems a quite place, a student alone, maybe under the duvet, maybe sat in the dark of their bedroom. "In virtual lab student can have there own time" so they feel in control of their destiny. They are able to say "I have just sat and completed it and actually understand it", surprised by the simplicity of something which was a struggle in a pressured class. For some they are able to focus "I would like to learn about virtual experiments like doing titrations and develop on my accuracy skills"; this student, then, realises the particular possibilities of the virtual laboratory. There is time and the internal space to "read pieces of information and gain a new understanding".

Student like the "quick to access" and "time saving", speeding up the slow parts of a practical lesson. Some find the virtual laboratory as "exciting" as the real one. One remarked "I also find work on the computer through simulations really helpful". So here it is the engagement with the task rather than the presence in the laboratory which is significant. For some students, the noise and action of the lab is oppressive. In fact, for one student "doing experiments in a lab make me nervous and panicked. I like doing them virtually"; the virtual laboratory provides a refuge. There is a safe space to try things out "and not mess it up" surrounded by others.

But the virtual laboratory is not for all; the small screen, the limited possibilities, the closeness of the experience is stifling. The tranquil study is broken by the insistent ping of messages or the laugh of a sibling watching TV in the next room. Concentration broken by the streetlight flickering, a radio, the smell of dinner. Frustration at unfamiliar words, or unclear instructions, no one to ask, "sometimes we need the teacher". Missing the opportunity to "work as a team together … supported by other students"

Results

Students have carried out experiments as part of their normal classes over the year. Due to the timing of the COVID lockdown it was not possible, to use a sophisticated approach to experimental timings or choice. The VL experiments were chosen to reflect RL experiments which the students had experienced earlier in the year, replicating some of the tasks in a virtual environment, these are shown in Table 2.

Experiments	VL experiments
Light reflection and refraction	https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html
Measuring focal length	https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html
Simple electrical circuits measuring voltage and current	https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html
Gravitational and kinetic energy exchange	https://phet.colorado.edu/sims/html/energy-skate-park-basics/latest/energy-skate-park-basics_en.html
Hooke's Law spring extension experiment	https://flashyscience.com/experiments/open/hookes-law
Free-fall due to gravity	https://flashyscience.com/experiments/open/freefall
Measuring heats of reaction	http://employees.oneonta.edu/viningwj/sims/calorimetry_s.html
Titration experiments	http://www.rsc.org/learn-chemistry/resources/screen-experiment/titration/experiment/2

Table 2 Showing the experiments which were used for the comparison of RL and VL. The experiments were carried out during the year, then the corresponding VL version was performed shortly before the questionnaire was answered.

The questionnaire shown in Appendix 1 and a similar one with alternative textual questions were given to students after each VL exercise. These VL were set from within a Google Classroom virtual learning environment (VLE), accessed remotely on students' own devices, the range of which are shown in Table 3 and Figure 2. Due to the college closure only remote assistance via email is possible.

Device	**Number of students using**
PC or laptop	14
iPhone	11
Android	3
Other smart phone	1
Chromebook	1
Another device	3

Table 3 showing the type of device each student has used to access the VL.

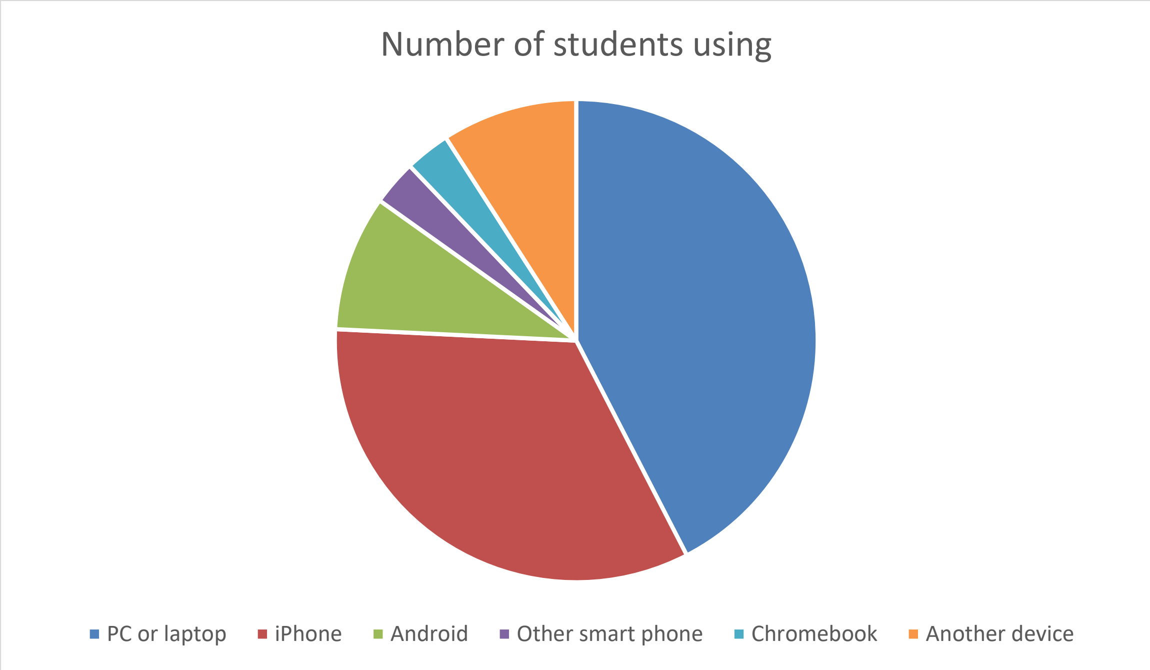


Figure 2 showing the proportion of each type of device that the students used to access the VL.

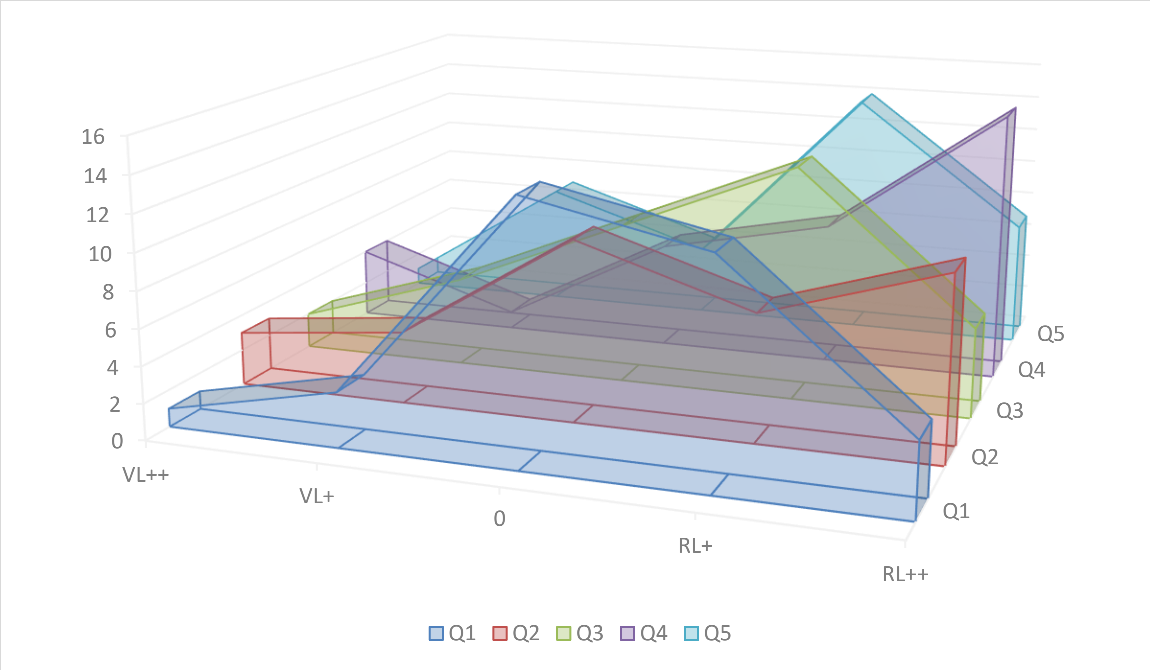
The Likert responses are given in Table 4; these have been rearranged in Table 5 and Figure 3, to show the responses to VL and RL more clearly.

Questions	**Strongly Agree**				**Strongly Disagree**
Likert score	**1**	**2**	**3**	**4**	**5**
Q1	1	3	14	12	4
Q2	10	7	10	4	3
Q3	2	5	9	13	5
Q4	15	8	6	1	4
Q5	1	7	4	14	7

Table 4 Showing the Likert score for each question selected by students in response to the questionnaire. Due to the wording the questions 2 and 4, have an opposite relationship to 1,3 and 5, see text. A copy of the questions is given in Appendix 1. Thirty four (34) responses were recorded (only 33 for Q5).

	Q1	Q2	Q3	Q4	Q5	Total
VL++	1	3	2	4	1	11
VL+	3	4	5	1	7	20
0	14	10	9	6	4	43
RL+	12	7	13	8	14	54
RL++	4	10	5	15	7	41

Table 5 Showing the Likert score for each question selected by students in response to the questionnaire. The table shows the preference +; or strong preference ++ for VL or RL in response to the questions. an opposite relationship to 1,3 and 5, see text. A copy of the questions is given in Appendix 1, the order of responses to questions 2 and 4, have been reversed to match the other questions. Thirty four (34) responses were recorded (only 33 for Q5).



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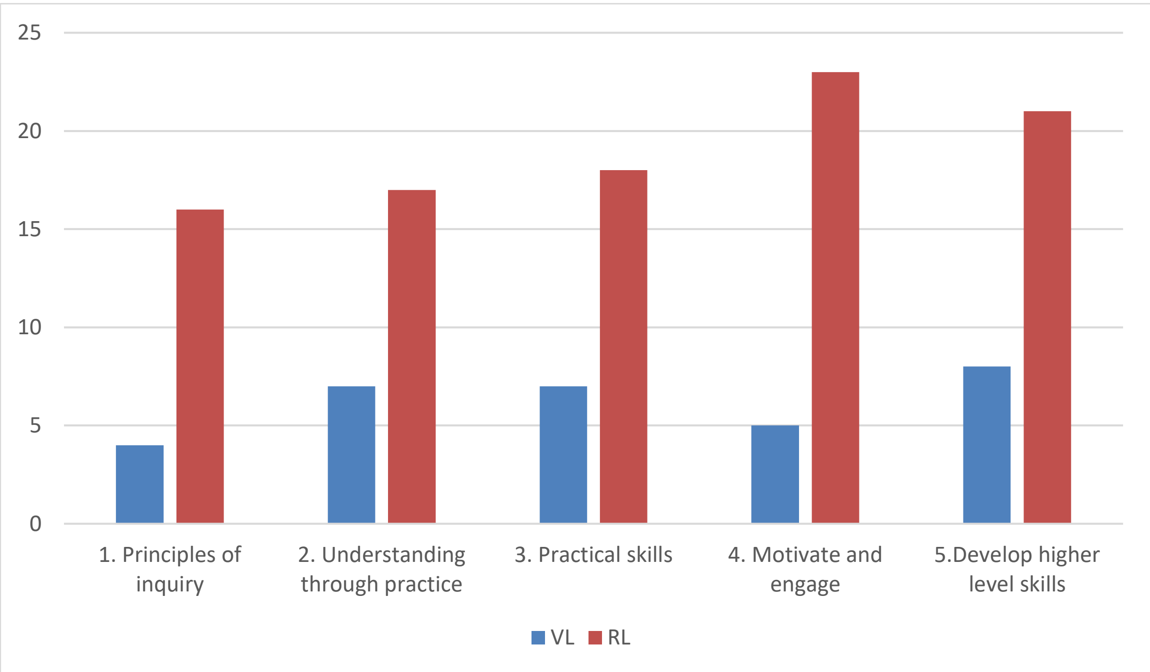

Figure 4 The Likert data is shown in the figure above, where only the combined preferences for each type of laboratory are shown (a total of 34 responses; neutral omitted).

Figure 4 shows a summary of the Likert data indicating a clear preference for learning in real laboratories. Looking at this figure and the full data in Figure 3, suggests that this preference is most extreme when answering Q2 and Q4.

However, students' textual responses are more favourable to the use of virtual laboratories than suggested by the Likert data. These responses are recorded in Appendix 3 (note that due to an error most of the responses to question 5 where not correctly recorded, so there are many fewer comments for this question). The results for each question are summarised in Table .

Q1 ***I learn more about the principles of scientific inquiry from virtual laboratories than from physical laboratories.*** The maximum Likert response is neutral, with a bias in preferences towards RL. Textual comments show the range of response. In favour of VL, students who" had trouble doing in class …just sat and completed it and actually understand it" also comments, that "I can also take my time to help me understand the theory" or "re-read pieces of information and gain a new understanding" this shows how the self-paced work benefits some students. For others, they "learn the same amount" or "both equally as good". However, a significant number felt they "learn more about the principles of scientific inquiry from a physical laboratory" because having "experienced doing it and will remember" more.
Q2. ***I gain more of an understanding of theory through practical experience using real rather than virtual laboratories.*** The Likert scores are the most evenly distributed for this question, however, again showing a skewed distribution favouring the RL. There are a similar range of comments to those for Q1. The VL is "helpful because I can use the simulations to help me understand how things work" and "virtual is good for the explaining". Again, many find "both are equally" good; however, for at least one "I didn't understand any theory since the remotely learning started" and another RL "gave me more understanding of theory."
Q3. ***Virtual laboratories teach me more practical skills, such as measurement and observation, than I learn in a physical laboratory.*** There is a skewed Likert distribution in favour of the RL. Again, there are differing views expressed: for some, the VL is better "because its a professional doing the experiment so all the little details" and "is a lot easier". Many of the students think it is "about the same" but for most they "don't think online labs teach more practical skills". In particular, "better measurement and observation skills because you are actually doing the practical"; "because I can actually use measuring tools or equipment" and "experiment physically so you can remember what your doing".
Q4. ***I feel more motivated and engaged using a physical laboratory rather than a virtual laboratory.*** This is the question which showed the largest difference in Likert scores between the two laboratories. The RL is seen as much more motivating and engaging, this is borne out by comments such as "good practice for future"; "Practicals are fun and actually doing them helps us remember the learning"; "we have contact with people we are able to engage more"; "work as a team together and are supported by other students" and "there is someone is there teaching me". Some value both approaches; while for a few they "feel more engaged using the virtual" and "online labs can be exciting because I can sit in my own time and take the time to practice"
Q5. ***I develop higher level skills and attributes, such as, communication, teamwork and perseverance; when using a virtual laboratory rather than a physical laboratory.*** There is again a clear bias in the Likert data in favour of RL. Comments like the RL "helps me increase my skills of working together as a team along with communication and perseverance", suggests that students value the social aspects of the laboratory.

Table 6 showing a summary of each of the five questions in the questionnaire (Appendix 1) given in Appendix 3.

Discussion

There is a bias in the Likert data for all questions in favour of the RL, as shown in Figure 4 (This contrasts the case for HE, see studies cited by Miller, Carver and Roy (2018)). The bias appears more distinct for Q4 concerning motivation and Q5 concerning skills. From the comments it appears that one important factor is that of the social interaction involved in the RL: this chimes with the social constructivist approach, (Gregson and Hillier, 2015, p. 48). Learning, as well as, motivation occurs due to the interaction of students in the physical environment; this is not replicated in the VL. Similarly, students recognise that "actually do it physically" helps gain "understanding using real practical experience". Sennett (2008, p 44) might describe this as "thinking like a craftsman". This recognition of the experiential follows the route suggested by Kolb, (Gregson and Hillier, 2015, p. 46-47) a concrete experience, followed by observation and reaction. There is also an appreciation of potential tacit knowledge (Redman, 1993) citing "good practice for future"; "work as a team together" and "better measurement and observation skills". Although the students may not be aware of the underlying educational theories, their comments tend to support the social constructivist thesis.

There are some students who prefer the VL and others who judge the two equally. Ideas like "exciting", "visual and personal", "gain a new understanding" suggest the value of the new technology.

The balance of the text responses is more evenly distributed than would be expected from the Likert data; it may be useful to speculate why this is the case.

Firstly, the virtual laboratory is often technology dependent, the students were using a range of devices, giving a range of experiences. Table 3 shows the devices students have used to access the VL. Due to the range of operating systems there is no guarantee of compatibility for all these devices. Additionally, around half of the devices are phones, thus with small screens. Personally, I find accessing VL on a laptop restrictive and would find using a phone very difficult.

Secondly, due to Lockdown, the students are exposure to unfamiliar ideas, procedures and software without adequate support. Students feel that "with physical labs I can get help in person" and "the teacher could always explain more on how to do it" and they are without "contact with people" where they "work as a team together and are supported by other students." As Sennett (2008, p 179) argues - in the "laboratory the spoken word seems more effective than written instructions".

Thirdly, student's language abilities may have an effect on the quality of their interaction with VL. Most of the students in this study have challenged language skills, either they have not achieved GCSE grade 4 and/or English in not their first language. VL instructions are written with HE or at least A level students in mind. This creates a language barrier to accessing the VL as well. It may be significant that the textual responses, presumably from those happier to write, are more favourable to VL than the numerical scores.

Fourthly, because the VL were all carried out after the RL, this may have influenced the results. Students may have welcomed that they "can take my time" in the VL to understand previous work or maybe bored by repeating tasks.

Finally, the effect of lockdown may influence a students' desire to be in a physical laboratory, as a proxy for a return to "normality". This may particularly be true as may have challenging social, physical or emotional environments while completing the task.

Overall, then we see from the data and comments that motivation and engagement are probably the big issues in implementing VL.

Conclusion

This limited study has suggested that there are a number of factors which affect how students view learning in a VL. When answering five questions about their learning in VL on a Likert scale there was a significant preference for RL. Textual answers to accompanying questions suggested students can be excited and motivated by new technology, but difficult to use technology or software cause issues. Unlike many university students, FE students may lack the physical, academic and emotional resources or resilience needed to make the most of the new opportunities. Language abilities may inhibit access to new ways of doing things. Some students value the physical laboratory "because sometimes we need the teacher": this need should be considered when implementing virtual applications for FE students.

There needs to greater understanding of both the intellectual and emotional experiences of learning through virtual laboratories, in order to achieve the successful implementation of virtual laboratories in FE.

Recommendations

This limited study has suggested a number of interesting findings, in order to verify these a more extensive study is required. A future study will need to ensure that any bias is removed from results, including an alternation of RL and VL, a consistent digital platform, student training and practical laboratory space. There will need to be a review of the questionnaire to ensure that the questions are targeted and valid. It will also be interesting to investigate the interaction of agency and presence in students' different learning environments.

The College plans to use VL as an integral part of science courses, in the coming term. I have tried to communicate the results of this work using the dissemination strategy described in

Appendix 5. Care needs to be taken during the planned implementation of VL to ensure these will enhance the students learning experiences. This will include as simple and consistent student interface as possible, with help readily available.

The technology, software, language and assessment need to be chosen carefully to ensure these align with the desired intellectual and emotional outcomes (Biggs, 2015). This will involve a planned approach, centred on students' learning needs. This work has suggested that this needs to include as much student interaction and co-learning as possible.

The outcomes chosen should reflect the value that practical science can give in educating FE students. Using the work of Holman (2017) as a guide will ensure that the outcomes identified are consistent with current best practice.

Implementation needs to be monitored reflectively; it is recommended that a study of the implementation process is carried out. This should be done concurrently, so that the findings of this study can be used "in real time". It will be important to achieve an enhanced understanding of the process. This will allow an informed crafting of the curriculum to match the desired outcomes and achieve the best use of virtual laboratories.

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Appendices

Appendix 1

The use of Virtual Laboratories in Further Education

This questionnaire asks you about your experience using both physical (real) and virtual laboratories. You will be asked to agree or disagree with a statement and then you have space to comment about the statement. When answering the questions think about your experiences in both the physical and virtual laboratories (L2).

How did you access the virtual laboratory

PC or laptop
I phone
Android phone
other smart phone
Chrome book
Another device

I learn more about the principles of scientific inquiry from virtual laboratories than from physical laboratories.

Strongly Agree

1
2
3
4
5

Strongly Disagree

Do you think you learn more about the principles of scientific inquiry from virtual laboratories rather than physical laboratories?

Your answer

I gain more of an understanding of theory through practical experience using real rather than virtual laboratories.

Strongly Agree

1
2
3

4
5
Strongly Disagree

Do you think you gain more understanding of theory through practical experience using real or virtual laboratories?

Your answer

Virtual laboratories teach me more practical skills, such as measurement and observation, than I learn in a physical laboratory.

Strongly Agree
1
2
3
4
5
Strongly Disagree

Do you think virtual laboratories teach you more practical skills, such as measurement and observation, than you learn in a physical laboratory?

Your answer

I feel more motivated and engaged using a physical laboratory rather than a virtual laboratory.

Strongly Agree
1
2
3
4
5
Strongly Disagree

Do you feel more motivated and engaged using a physical laboratory rather than a virtual laboratory?

Your answer

I develop higher level skills and attributes, such as, communication, teamwork and perseverance; when using a virtual laboratory rather than a physical laboratory.

Strongly Agree

1
2
3
4
5

Strongly Disagree

Do you feel you develop higher level skills and attributes, such as, communication, teamwork and perseverance; when using a virtual laboratory rather than a physical laboratory?

Your answer

Submit

Never submit passwords through Google Forms.

Appendix 2

INFORMATION FOR PARTICIPANTS

Participant Information Sheet

1. Research Project Title

The virtual science laboratory in Further Education.

2. Invitation

You are being invited to take part in this research project. Before you decide to do so, it is important you understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

3. What is the project's purpose?

This research project aims to investigate the effectiveness of virtual laboratories in further education.

4. Why have I been chosen?

You have been chosen because as a student of The Sheffield College you are involved in laboratory based learning activities.

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be able to keep a copy of this information sheet and you should indicate your agreement to the online consent form. You can still withdraw at any time prior to data analysis. You do not have to give a reason.

6. What will happen to me if I take part?

You will be asked to participate in a short questionnaire, this will be given to you to complete. This should take approximately 10 minutes. The window for completion of this questionnaire will be 2 weeks (10 working days).

7. What do I have to do?

Participate in the questionnaire. There are no other commitments or lifestyle restrictions associated with participating.

8. What are the possible disadvantages and risks of taking part?

Participating in the research is not anticipated to cause you any disadvantages or discomfort. The potential physical harm or distress will be the same as any experienced in everyday life.

9. What are the possible benefits of taking part?

A possible benefit to participating in this study could be firstly, better understanding of the virtual application of practical activities and how they inform your learning.

10. What happens if the research study stops earlier than expected?

Should the research stop earlier than planned and you are affected in any way we will tell you and explain why.

11. What if something goes wrong?

If you have any complaints about the project in the first instance you can contact me. If you feel your complaint has not been handled to your satisfaction you can contact any member of the Senior Leadership Team/Safeguarding/Human Resources at The Sheffield College.

12. Will my taking part in this project be kept confidential?

All the information that we collect about you during the course of the research will be kept strictly confidential. You will not be able to be identified or identifiable in any reports or publications. Your institution will also not be identified or identifiable. Any data collected about you in the questionnaire will be stored online in a form protected by passwords and other relevant security processes and technologies.
Data collected may be shared in an anonymised form to allow reuse by the research team and other third parties.

13. Will I be recorded, and how will the recorded media be used?

You will not be recorded in any way other than your input to the questionnaire without separate permission being gained from you. Field notes will be taken during the research but will not contain any identifiable information.

14. What type of information will be sought from me and why is the collection of this information relevant for achieving the research project's objectives?

The questionnaire will ask you about your experience and opinions of using real and virtual laboratories.

15. What will happen to the results of the research project?

Results of the research will be published. You will not be identified in any report or publication. Your institution will not be identified in any report or publication. If you wish to be given a copy of any reports resulting from the research, please ask us to put you on our circulation list.

16. Who is organising and funding the research?

The project is a partnership with Sunderland University and the Education and Training Foundation. The research supervisor for this project is Robin Webber-Jones (robin.webber-jones@sheffcol.ac.uk).

17. Contacts for further information

Dr Neil Peirson, (neil.peirson@sheffcol.ac.uk) City Campus, Granville Rd, Sheffield S2 2RL

Thank you for taking part in this research.

Neil Peirson
Lecturer in Applied Science
MA short course in Educational Research (Sunderland University)

PARTICIPANT CONSENT

I.. voluntarily agree to participate in this research study.

Signature of research participant

-- ----------------

Signature of participant Date:

Signature of Researcher: Neil Peirson

I **Neil Peirson** believe the participant is giving informed consent to participate in this study

Research Project Date:

Appendix 3

1a. Do you think you learn more about the principles of scientific inquiry from virtual laboratories rather than physical laboratories?

No

No because i like to be hands on

I think so

I think they are both equally as good. For some topics it is easier learning online than to in front of a teacher. For example the simple circuits experiment i had trouble doing in class however i have just sat and completed it and actually understand it.

No, it’s very hard to understand anything. I’m really struggling to do any work. I really prefer physical laboratories

No i learn more in physical laboratorys

I think I'd learn the same amount

is useful but, but is not the same thing because sometimes we need the teacher helps and explation

No

In a way because it is more visual and personal.

No not necessarily any more but I do like them

No

Yes, as I can re- read pieces of information and gain a new understanding. I can also take my time to help me understand the theory etc.

I do not know

no

No, still think that physical laboratories are better.

1b. Why do you think you learn more about the principles of scientific inquiry from a virtual or physical laboratory?

from both, but still think physical labs are more efficient

It’s good that you can go through it more then once and not have to spend time clearing experiments up .

Learn more from physical as you can ask question and actually do it physically

I think that I learn more on virtual because it shows how the practical is carried out perfectly but in developing skills, physical is the way to go

Physical laboratory

how to calculate and plot it on a graph and more

It was easier to understand watching the graphics through my phone

I learn more from physical laboratory because it is hands on

A lot of things based on physical

Because I can acess the work in one place and take as long as I want

I learn both of them equal

physic laboratory was more easy let me understand what i need to do

physical laboratory

Physical laboratory

I will learn more about the principles of scientific inquiry from a physical laboratory because I have experienced doing it and will remember it than from a virtual laboratory

2a. Do you think you gain more understanding of theory through practical experience using real or virtual laboratories?

Yes

Real laboratories

Again it's way better to have a teacher who explains and support you in the class while on virtual laboratories is just a mess for me. I didn't understand any theory since the remotely learning started

Personally I learn better through the virtual lab because its much more easier and I can re read instructions and take my time alone. I think its an easier way of learning

Practical experiences

Real Laboratories

I think I learn from both as the practical is good to understand what you are doing but virtual is good for the explaining

Yes

I think that watching the video and someone explaining it to me will help me understand the project more

both

I'm unsure.

I think both are equally as gaining as during a practical I can work with new materials and do the work in person, where as through a virtual lab I can take my time and have unlimited resources if I struggle.

2b. Please give an example of where, you think you gain more understanding of theory, through the practical experience of using a real or a virtual laboratory.

Accuracy In the experiment

Like the videos and the animation in virtual lab

I gain more understanding of the practical virtually because the experiment has already been layed out and done perfectly for you so there are no mistakes

Understanding the way kinetic and potential energy vary consequently the movement

When your doing it practically

Real

in a real lab i learned how to measure distance of objects such as the speed of moving vehicles, and in the virtual lab, i learned how to calculate and plot them on graph and research my projects more actively.

Especially for physics its helpful because I can use the simulations to help me understand how things work

The real laboratory gave me more understanding of theory.

Following step by step

real a laboratory.

in real laboratory, i can easy understand what i need to do after teacher show for us how to do

Real

3a. Do you think virtual laboratories teach you more practical skills, such as measurement and observation, than you learn in a physical laboratory?

No

I dont think online labs teach more practical skills because thats just better and more easier doing it on paper with someone instructing you

About the same

Yes

Doing it myself teach me better as I get to do it and practice it to understand it and remember it better

No I think the practical is good for the measurement and observation as it good to see the trail and error

i think is half , because some theory or lesson are easy in virtual than physical and vice and versa

Yes because its a professional doing the experiment so all the little details will be made clear

No

It teaches about the same.

No because its harder as its online and you can be 100% accurate.

3b. How does a virtual or physical laboratory teach you more practical skills, such as measurement and observation?

Your doing the experiment physically so you can remember what your doing

Virtual is a lot easier however it’s more difficult with physical but it’s better practice.

Physical laboratory definetly gives you better measurement and observation skills because you are actually doing the practical

How does a virtual or physical laboratory teach you more practical skills, such as measurement and observation?

Physical labs are more helpful in the aspect because I can actually use measuring tools or equipment etc

through measuring objects, and researching online and checking if my result is wrong or right.

Don't know

It helps you build more skills doing of doing measurements

In a physical lab if you don’t understand how to measure the teacher could always explain more on how to do it.

I like doing it practical

.

And working as team

the physic labtory teach me how to measure and recoed the result

4a. Do you feel more motivated and engaged using a physical laboratory rather than a virtual laboratory?

Yes

No, I have bad internet connections and I’ve been really disappointed with learning I could hardly assign anything and most of them done late

I think I like they both equally because I can just log onto the computer and do work and quickly understand during my own time but then sometimes it can be harder due to the topics. Practicals are fun and actually doing them helps us remember the learning

Becasue there is someone is there teaching me

I don’t know

Yeah because its more fun that watching someone else do it

Yes

yeah, is more fun

No, I feel more engaged using the virtual.

Yes I do

Of course . If the meaning of physical laboratories is the real laboratories because I did not understand their meaning

Not as such because online labs can be exciting because I can sit in my own time and take the time to practice and read the work and complete it.

4b. What motivates and engages you when using a physical or virtual laboratory?

Getting the accurate results. If you do something wrong in a physical experiment you Amy have to start the whole experiment again but with virtual you can just start that part again .

Physical, it’s good practice for future

physical labs becauase we have more contatc with the equipments

Physical laboratory is more motivating in my opinion because you're carrying out the experiment for yourself and so its most likely more fun

Physical laboratory

Using a virtual lab I find it easier to get online and get started but with physical labs I can get help in person

to learn something new

Yes it’s better to do more practical stuff than other because you know what your doing in practical than virtual

Physical laboratory we have contact with people we are able to engage more

You learn to work as a team together and are supported by other students.

we can see the real equipment in a physical labtory which i can understand how to use them and how to do the experiment

.

Physical

5a. Do you feel you develop higher level skills and attributes, such as, communication, teamwork and perseverance; when using a virtual laboratory rather than a physical laboratory?

5b. Which higher level skills (e.g. communication, teamwork and perseverance) do you feel you develop when using a virtual or physical laboratory?

All of them

Physical laboratory helps me increase my skills of working together as a team along with communication and perseverance. This is because your actually talking to other people who are in the same position as you and it also makes the experiments more enjoyable.

physical laboratory?

All of them

Physical

physical laboratory

Appendix 4

The answers to the questions (***in italics***) are recorded verbatim for each student, who is identified by a single letter, following their answer.

What I would like to learn? What practical scientific skills would you like to learn? What would help you get the job you want?

I'be applied for health and science access course so I want all the useful Topics that would help me next year please M

I would like to learn about all sciences. Mainly forensics as that is the future job goal I am aiming for. P

More things related to my course that I am. Plus the skills needed to work in a hospital lab O

more practice on scientific practicals L

researching , planning experiments and then doing experiments with techniques. By doing hard work. K

I would like to learn about virtual experiments like doing titrations and develop on my accuracy skills. J

How I would like to learn practical science? Do you like being in a lab?

Do you like being in a lab? Yes. N

Yes, I don't understand the practical when I see it as much as I understand it when I do it M

Yes O

I love being in a lab but I also find work on the computer through simulations really helpful. P

Yes L

I really like doing experiments and I love being in lab. K

I like being in a lab but doing experiments in a lab make me nervous and panicked. I like doing them virtually. J

Yes Q

What are the best things about a real lab?

You know how to do it so you understand it better M

See real, not hypothetical results N

I can communicate with people around me and the teacher which helps. I can also work with materials etc P

You can work in teams and it hands on O

dealing with real chemicals and equipment L

Is that collecting datas and teasing them with a different techniques. K

You can do the experiments hands on. J

You get to actually see what’s going on Q

What have you learnt in a real lab?

Teamwork, health and safety and other skills M

Many things, including adherence to laboratory rules N

I have learnt how to correctly do simple measuring skills and know how to work with equipment P

Team work, experiment's that I have done while in college O

how to handle different scientific equipment L

Good team working skills. developing practical skills. K

Different types of equipment and how to use them. J

The safety procedures for when doing an experiment Q

What are the best things about a virtual lab?

You can rewatch it M

Actually, I don’t know N

I can take my time and complete the work as fast or as slow as I want. I can also go back and forth. P

Nothing I don't like it O

time saving and clear instructions to follow L

In virtual lab student can have there own time and they can understand all techniques which they are learning in that time. K

People’s life and safety isn’t at risk. J

It’s quick to access and doesn’t make mistakes Q

What have you learnt in a virtual lab?

Nothing M

I have learnt about reflect angles. P

Not much O

more practice in scientific practical L

The fist thing I have learned is that the safety is first and secure yourself as well. I have learned how we can do experiments and which techniques we have to use. Also, how we can work as a team in lab Safely. K

How to do titrations and not mess it up. J

How to do the experiments Q

Appendix 5

Dissemination strategy

I set up a Google Classroom with access for the science staff in the department. To this I have added a number of resources, including the access details and reviews of a range of virtual laboratories. I have also written a report for managers setting out a range of options for implementing VL within the College. This work has been the subject of several meetings to discuss implementation in the College.

My poster has been presented at the Education and Training Foundation Virtual Annual Education Research Conference 2020.

I have approached the editors of 'Intuition' concerning the possibility of contributing a short article about this study.

Taking the work forward I hope to continue the research. I may be able to contribute towards a staff development event within the College based on the results of an implementation study.