PHYS7000 - Masters Thesis

How does students having additional preparation material prior to their laboratories effect student confidence and interest?

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Abstract

Social virtual reality shows promise in the field of physics education and higher education more generally, but it is unclear how effective it is compared to other teaching methods. This study investigates the effect of social virtual reality and pre-recorded videos as extra pre-laboratory material in addition to lab-scripts on student confidence and interest.

It was found that the pre-lab video material leads to overwhelmingly more self-reported student confidence and interest compared to the virtual reality experience in their respective labs, this is likely to be because the VR experience did not have any guidance leading to the students not gaining anything from it.

This study also attempted to evaluate if more active pre-lab preparation materials were more effective at increasing student confidence and interest but the results were inconclusive due to the difficulty of comparing the video and VR labs results fairly. The unfairness came from the limited time to create VR labs and videos for both labs, instead it was only possible to make one for each therefore it was very difficult to compare.

The design choices for putting together the virtual environments do make quite a difference, this study shows that you can design environments to help students unknowingly perform particular productive behaviours. For example putting two pieces of related equipment near each other but with enough distance that it requires two people to operate both, therefore this incentives teamwork.

Finally it was seen that students get quite confused with the required lab-scripts provided in the lab module due to their varied designs.

Further research is needed which could include working out which types of virtual environments work the best for teaching, and looking into if the quality of editing in video materials makes a difference to their usefulness.

Contents

1 Background

Over the last 5 years global events such as COVID-19 have disrupted classrooms, teaching laboratories, and workshops. This led to educators using live streams, pre-recorded material, and considering new technologies like virtual reality. Most students were happy when lockdown ended and everyone returned to in-person methods of teaching, although this doesn't mean that new technologies and other teaching methods cannot be used in addition to traditional in-person teaching methods to provide students with the greatest opportunities to learn.

1.1 Virtual Reality

Virtual Reality is an emerging technology that shows promise in the field of Physics Education, and more generally Education as a whole [1]. Virtual Reality (VR) is where technology is used to create the experience that the user is in an environment that they are not and is usually not real. Interactive Virtual Reality (I-VR) is the same as Virtual Reality with the addition that the user is able to directly interact with the environment. In this paper I-VR is referred to as VR, This is because most people think of head mounted displays (HMDs) when they think about Virtual Reality. Modern HMDs have 6 Degrees of freedom (6 DOF), this means the headset is tracked in position (3 DOF) and in rotation (3 DOF) relative to the physical space. This allows modern VR HMDs to feel incredibly immersive as the user can physically move around in the virtual space as if they were really there. The most available and affordable modern VR HMD is the Meta Quest 2 Headset [2]. The quest 2 has two spatially tracked controllers also with 6 DOF, allowing the user to interact with the virtual environment using their hands.

Other studies have been investigating the benefits to using Virtual Reality in Education and Higher education in other disciplines, these disciplines include: Computer Science [3], Public Health [4], Bio-medicine [5], Education [6], Psychology [7], Business [8], Engineering [9], and Geography [10]. Although the use of Social Virtual Reality in Physics Education and Education is an unexplored space. Social VR is where the virtual environment is shared between multiple users all with their own VR Headsets. This adds a huge layer of complexity due to programming the networking for syncing the clients and is likely the reason social VR is less explored. Instead of developing the VR experiences directly in a game engine like Unity [11], a VR social platform was used. The ConVRse VR Social Platform was chosen as its the VR social platform which the principal investigator was most familiar with as it was developed by them [12]. This meant that the development of the virtual social environments could begin almost immediately without having to worry about the complexities of networking.

Virtual reality can be used as a unique accessibility tool for example for students who have less mobility [13] or even for better communication for students which are hard-of-hearing by displaying virtual sub-titles (although more research needs to be done on this in the future).

1.1.1 The ConVRse Platform

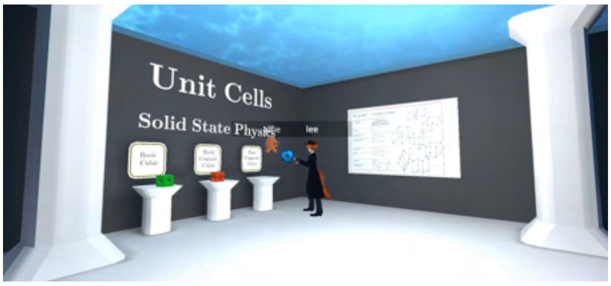

Figure 1: The ConVRse Social Platform with people talking about unit cells with one of them holding one.

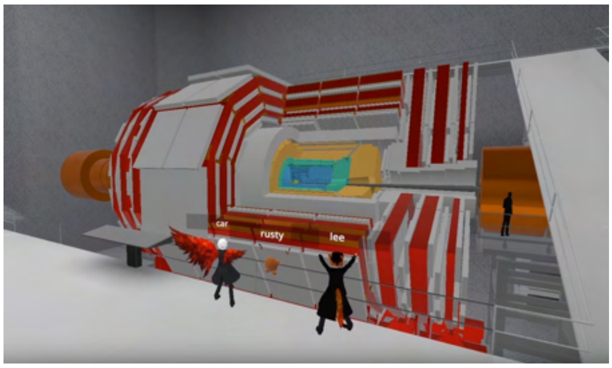

Figure 2: The ConVRse Social Platform with people looking at the Compact Muon Solenoid (CMS) from CERN [14].

ConVRse is a Virtual Reality social platform that allows for the creation of virtual environments and avatars. Using ConVRse for this project offers a lot of flexibility as it was created by the principle investigator, knowing the platform inside and out offers a huge benefit of not having to waste time to learn how to do certain tasks such as creating the virtual environments. The masters research project has very limited time therefore this is ideal.

ConVRse handles the networking of the world itself, the avatars, the items, and any experiment related data that needed syncing and makes it easy to get multiple users in separate headsets into the same virtual world/environment. Examples of this can be seen in figures 1 and 2.

This is the first time ConVRse has ever been used for research purposes but it is certainly up for the challenge as it has all the required features for this study.

1.2 Active vs Passive Learning

It has been suggested in academic literature that when students actively engage with material (Active Learning), they are more likely to do better than passively taking in the material (Passive Learning) [15]. Active Learning is where the student has to "do a thing" to understand the topic, and includes activities like: problem sheets, workshops, and labs. Whereas Passive Learning is where the student is exposed to the information but does not have to do anything, and this includes activities like: Lectures, reading a book, watching a video.

Different pre-laboratory material/activity methods take different amounts of work on the lecturers behalf to produce said material/activity. One possible perspective on "the difficulties to produce a material" VS "how passive or active that material is" for a few example methods can be seen in figure 3.

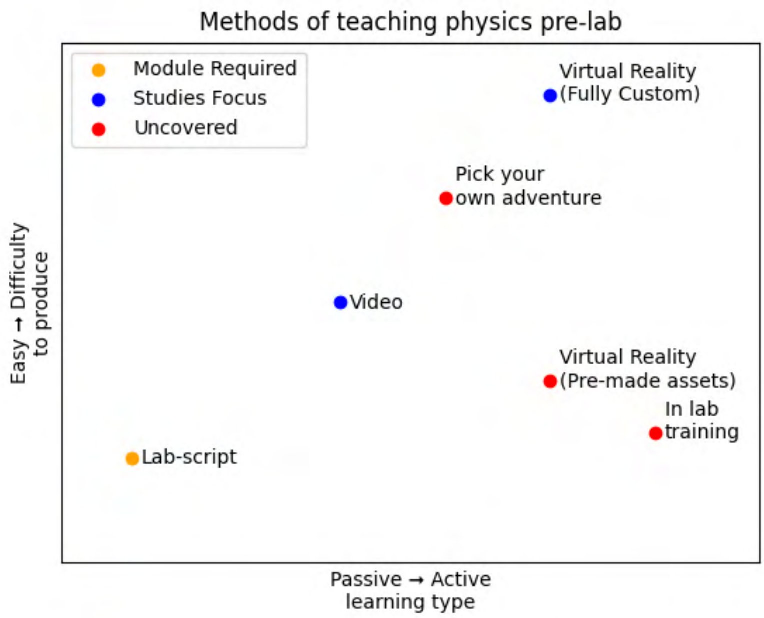

Figure 3: A possible perspective on how difficult it is to produce different pre-laboratory material.

Opinion breakdown of the placement of each material/activity in figure 3:

- Lab-script

  The lab-scripts are documents that give detailed instructions on how to do the experiment and usually some background. These are easy to produce because academics are used to producing documents in this format. Lab-scripts are very passive as they only require the student to read them, although some lab-scripts do include pre-lab tasks which can make them more active as they make the student do a something active.

- Video

  Video pre-materials are recordings of instructions or tips about the laboratory. These are generally more difficult to produce than a lab-script as it can require careful thought on what is going to be in the video and its order, but also the camera angles, microphone quality, video length, editing for diagrams and explanations. These considerations can be dropped but potentially at the cost of the videos quality. Videos are also passive as the student only watches it [16], but it can be placed slightly more active as it could be considered common for students to take notes while watching video material, which makes it more active.

- Pick your own adventure [17]

  Pick your own adventure usually comes in the form of a tree of videos, where at the end of each video the student selects an option, which for example could be different outcomes of doing a step in an experiment. These are more difficult to produce then singular video materials because all the same considerations as singular videos but for multiple videos instead. In the case of an experiment every single possible option and outcome would need to be recorded and explained. Pick your own adventure is an active form of learning as it is continuously checking if the student understands each concept as it introduces it, this experiential learning approach opens the door for the student to make mistakes.

- Virtual Reality (Fully Custom)

  Virtual reality can be used to create a virtual lab that behaves in the same way as a real lab. A fully custom lab requires it to be created from the ground up, this includes: models, scripts, behaviours. This makes the VR lab quite difficult to create as it requires lot of knowledge related to VR Experience development. Virtual reality is more active than "Pick your own adventure" because the students are fully in control, It is essentially a fully simulated laboratory with no guidance. Although there is no guidance there is no risk of error meaning students should feel more comfortable with experimenting.

- Virtual Reality (Pre-made assets)

  This is the same as Virtual Reality (Fully Custom) except in the future there maybe platforms similar to Microsoft PowerPoint [18] that let you easily build VR experiences without having to have the required knowledge related to VR Experience development.

- In lab training

  In lab training is where the student is in the real laboratory with an educator who runs the student through the experiment. This is usually quite easy to setup, although complications can come from scheduling, and if it is being ran with multiple students at once safety need to be considered more carefully depending on the lab as its likely students will be crowded in a small space. In lab training is the most active form of pre-laboratory material because if students are allowed to play with the equipment they will have hands on experience with the lab with pointers from the educator.

1.3 The Study

This study will investigate whether or not the use of social virtual reality or an informational video (Shown in blue on figure 3) as pre-laboratory preparation material positively impacts student confidence and interest in the given laboratory.

The Stage one lab module(PHYS3700) was selected as it has a large potential participant pool, In addition these labs would be the easiest to mitigate any issues that could occur due to how early they are in the degree.

The PHYS3700 module is a stage 1 module which is broken up over the first two terms, the second part of the module is likely the first full labs the students have taken of their degree. Therefore it is used to teach students the right way to conduct labs and write reports. The term 2 part of the module contains 5 experiments which the students will do 4 of in the term. This modules labs being in the second term is ideal because this gave enough time in the first term for the VR environment to be created, ethics to be approved, and surveys to be written. The PHYS3700 contains the following labs:

- Exp. A - Rotation Rate of Mercury
- Exp. B - Stress and Strain
- Exp. C - Deduction of a Law
- Exp. D - Probability
- Exp. F - Diffraction Grating Spectrometer

Each student had a different Rota through their 4 out of 5 experiments setup by the module convener.

The students were given a lab-script which explains how to conduct the given experiment and also contains some questions to help guide their understanding and report writing. The students had two weeks to finish each lab with one lab session each Monday. They were expected to submit a 1500 word lab report each fortnight.

This study only run for 2 out of the 4 experiments they needed to do for this module, out of the experiments Deduction of a Law was selected for creating the virtual reality lab due to its simplistic nature, this led to confidence that it could be created within the time constraints. In addition Diffraction Grating Spectrometer was selected to be used for creating the informational Video. There was no specific reason this was chosen.

The experiments in PHYS3700 were run in pairs of students, they were able to help each other while running the experiments and collecting data but they must write and hand in individual reports. The students only share lab results. This requirement of pairs means that the use of a VR Social platform for recreating Deduction of a Law lab is ideal because you can get pairs of students in the same virtual lab like their real labs.

1.3.1 Details of the selected experiments

1.3.1.1 Exp. C - Deduction of a Law

Deduction of a law [19] was an experiment designed to teach students to find the relation of between three different properties of hanging plates and the time period of those plates when used as pendulums. These properties are:

- Size
- Density
- Depth / Thickness

Students were not given too much direction in the lab and are instead incentivised to experiment with the different plates to find the relationships between those properties and the time period of the corresponding pendulum.

Figure 4: Various plates that are available to the students for Exp. C - Deduction of a Law.

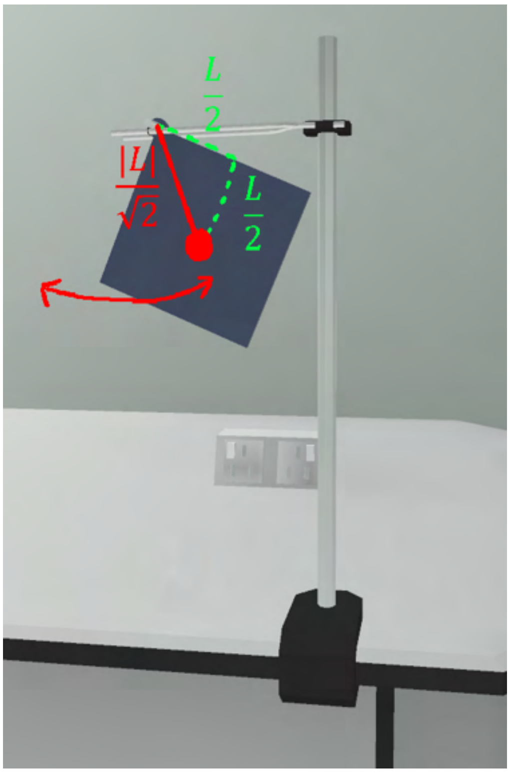

Figure 5: Diagram showing how a plate can be treated as a simple pendulum where the bob is at the plates centre of mass. This Diagram was made using an image of the virtual lab as there were no good real images available.

The equipment for Deduction of a Law is:

- Various plates (Figure 4):
  - Metal plates which vary in size and mass.
  - Plastic plates which vary in density, size and mass.

- Plastic plates which vary in depth/thickness and mass.

- 1 x Pendulum stand.
- 1 x Electronic balance.
- 1 x Stopwatch.
- 1 x 30cm ruler.

The goal of Deduction of a Law is to find out that only varying the size of the plate effects the time period. This is because the plate can be described as a simple pendulum where the centre of mass of the plate is the bob and the length of the pendulum is the distance from the centre of mass and the anchor. Once the relationship between the size of the plate and the time period is known it is possible to calculate what the value of gravity is, this is the final task of Deduction of a Law. The students should fine an equation which looks like this:

$$T = 2\pi \sqrt{\frac{\frac{2}{3}L^2}{g\sqrt{2\left(\frac{L}{2}\right)^2}}} \tag{1}$$

Where T - Time Period, L - Length of plate, and g - acceleration due to gravity.

Students should be able to derive this equation by using the hint sheet which is provided with the lab-script for Deduction of a Law.

1.3.1.2 Exp. F - Diffraction Grating Spectrometer

Diffraction Grating Spectrometer [20] was an experiment designed to allow students to verify what they have been taught in the class room about Spectroscopy. While also giving them an opportunity to use finicky equipment, which is generally a good experience in the lab as it re-enforces to the student that when running an experiment they must do everything they can to reduce the error.

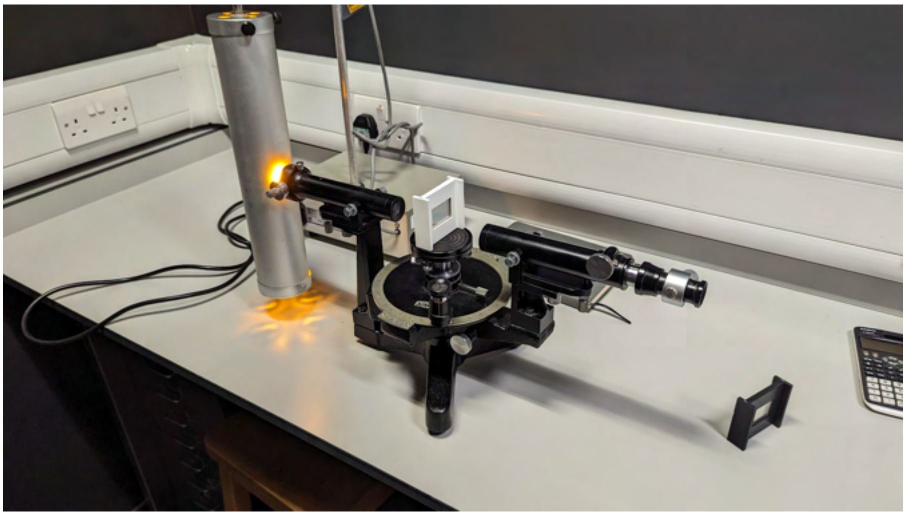

Figure 6: Diffraction Grating Spectrometer experiment Setup with Sodium discharge tube and 600 lines/mm diffraction grating.

The equipment for Diffraction Grating Spectrometer is:

- 1 x Helium Gas Discharge Tube.
- 1 x Sodium Gas Discharge Tube.
- 1 x Mercury Gas Discharge Tube.

- 1 x Cadmium Gas Discharge Tube.
- 1 x Spectrometer.
- 1 x 600 lines/mm Diffraction Grating (white).
- 1 x 300 lines/mm Diffraction Grating (black).

To run the experiment students must first calibrate the experiment by placing the diffraction grating they are interested in onto the spectrometer and lining up the centre bright line with zero degrees on the spectrometer. A sanity check can also be done by calculating where one of the known emission lines are for that gas by using equation 3 and checking if it is there as the expected angle. Equation 3 can be rearranged from equation 2 which is in the lab-script.

$$\lambda = \frac{d \cdot \sin(\theta)}{m} \tag{2}$$

$$\theta = \arcsin\left(\frac{\lambda \cdot m}{d}\right) \tag{3}$$

1.3.2 Scheduling

Fortunately the module convener of PHYS3700 agreed to make sure any students that signed up would:

A. be doing those two experiments.

   Exp. C and Exp. F are the only two experiments that this study is making extra preparation material for.

B. be doing them first.

   If the participants do not do these experiments first there will not be enough time in the term to run the experiment and write up the conclusions.

1.4 Cognitive Affective Model of Immersive Learning (CAMIL)

The Cognitive Affective Model of Immersive Learning is a relatively new model for understanding how to teach in Virtual Reality Environments, published in early 2021 [21]. This study uses the CAMIL to help interpret some of this studies findings.

The CAMIL lists several factors which influence the effectiveness of knowledge transfer in VR [21], these include (in terms of VR education):

- Presence

  Presence is the feeling of "being there". Higher presence can help the learner to focus on the VR task, without being distracted by the VR technology itself. Presence is limited by the VR hardware and software, to increase the feeling of presence it is usually easier to tackle the software side, making the environments more real and most importantly making the controls more fluid and less disruptive. This could involve placing something on something else instead of just clicking on a button. Ideally you want to make the environment behave how the learner expects it to, reducing friction between the real and virtual worlds.

- Agency

  Agency is the feeling of being able to affect the VR environment. Interactive virtual reality like the kind used in this study allows educators to create environments which learners can fully interact with. This could range from being able to pick something up to being able to run an entire experiment entirely within the virtual environment. Higher levels of agency can lead to better learning outcomes because it makes the VR experience an active learning process. Although too much agency can reduce learning outcomes because without guidance learners can get distracted by the virtual environment, therefore environments should be very carefully designed to reduce the risk of this.

- Interest

  Interest is the learners individual interest in the content. Virtual reality has a unique and powerful way to trigger learners situational interest in the topics, this is because the learning environments can be fully customised to suit the learning objectives. When learners are more interested in learning material they are more likely to take it in.

- Intrinsic Motivation

  Intrinsic Motivation is the learners motivation to engage with the activity itself. Virtual reality technology currently has a lot of hype due to recent products like Meta's Quest 3 [2] and Apple's Vision Pro [22], Hype around VR is currently enough to get learners really interested but work should also be done to make learning environments as exciting as possible while still providing good learning outcomes. Hype in VR can be seen by the number of recent articles published by mainstream media [23].

- Self-Efficacy

  Self-Efficacy is the learners perceived self ability that they will succeed in the learning task. Virtual reality allows educators to simplify the material they are trying to teach to its bare bones, removing all potential distractions leading to a more clear task therefore higher self-efficacy. In addition Virtual reality environments can be more guided which can also increase self-efficacy. Finally the learners know that the VR environment is a simulation, therefore it makes them less afraid to make mistakes which could also lead to a higher self-efficacy.

- Embodiment

  Embodiment is similar to presence but with the focus on the sense of being embodied in a virtual avatar, This means the learner has the feeling that they have a virtual body in the VR environment. The design of the VR Environment will not effect this, but educators can choose VR Platforms that have virtual avatar systems built in. In the case of this study ConVRse [12] (The VR Social platform used in this study to host the virtual environments) has an avatar system to give learners a virtual body.

- Cognitive Load

  Cognitive load is the number of things a learner can simultaneously think about, if they are given too much to process at once it is called Cognitive overload. Cognitive overload is very bad because it becomes very difficult to learn anything if the learner is overloaded. Virtual Reality poses a risk to easily overload learners especially if they are not used to VR, this is because they are not only focusing on the learning task but also on how to use VR itself and interact with the environment. These issues can be reduced if the virtual environment behaves more like how the learner expects, if it does not it could draw their attention away from the learning task.

- Self-Regulation

  Self-Regulation is is the learners own ability to keep themselves on task. In Virtual Reality this can be challenging especially if the learner is new to virtual reality and may want to mess about. Learning environments can be designed to be more goal orientated this can be done through gamification (Gamification is where you turn a non-game task into a game [24]) for example.

2 Method - Material Design

2.1 Virtual Lab Design - Deduction of a Law

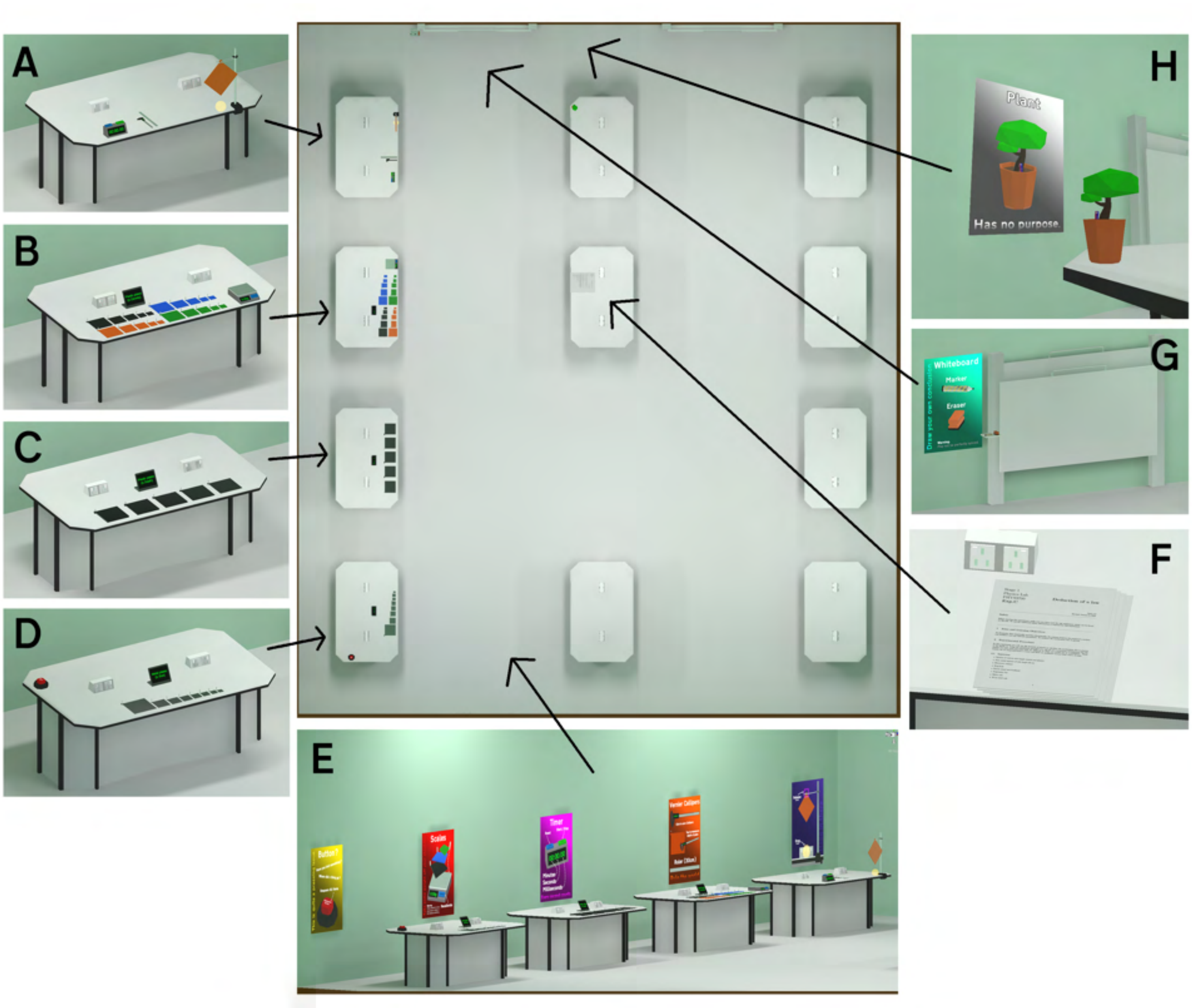

Figure 7: Virtual Lab

2.1.1 Technical details

All of the assets were created using blender [25], a 3D modelling program. Then Unity [11] was used to put the assets together, bake the lighting (baking is where the world is optimised and saved to look good while running on low-end hardware), and to add behaviours to the laboratory.

The Virtual lab environment were loaded into the Virtual Reality Social Platform ConVRse [26], which was used to run the virtual experiment.

2.1.2 Object placement

As shown in figure 7A, the Stopwatch (Left) and the Pendulum (Right) are on opposite sides of the same table. This was an intentional design choice to try and encourage the participant pair to work together as it is awkward to swing the pendulum and start the stopwatch at the same time, therefore only one will be done at a time. This essentially limits the CAMIL's Agency a bit to try incentivise teamwork.

2.1.3 Posters

Posters were placed behind the tables with useful information on them as shown in figure 7E.

These posters were designed to give information about how to use each piece of equipment in an eye catching way. These posters included information such as:

- How to use and read the timer.
- How to use the Scales.
- How to use the Vernier Calipers.
- How to write and erase on the whiteboard.
- How to return all the items.
- Reinforcement that the plant is there for no scientific purpose.
- How to detach and swing the plate on the pendulum.
- How to use the Virtual Reality controllers.

Figure 8: Virtual Reality Laboratory Posters

Each poster has a silly tagline on it related to what it is, these taglines were added to try and make the posters more catchy and fun to look at [27]. In addition if a student read one poster, they might be curious about what the other taglines are incentivising them to read all the posters out of curiosity.

2.1.4 The plant

A plant was added to the virtual lab to give students an item they could interact with and learn the controls without the worry of losing it, as shown in figure 7H. A plant was chosen as it is quite out of place compared to the rest of the experiment, this was to make sure that the students did not think it was relevant. Just in case a poster was created to re-enforce that the plant “has no purpose” in the experiment as shown in figure 8.

2.1.5 Lab-script

The full lab-script and a hint sheet was included inside the virtual lab as shown in figure 7F. The Lab-script was 3 pages long, and the hint sheet was a single page. These resources were available to all students taking this module. They were not modified in anyway, they were simply added as digital copies. This was done because the students usually have access to the lab-script within the real lab, it would be unreasonable to expect the students to have memorised it when entering the virtual lab.

2.1.6 The Whiteboard

A functional whiteboard was included as shown in figure 7G. This was so participants could jot down notes or anything they thought was important, a whiteboard also makes it easier to communicate ideas with their lab partner.

The whiteboard has a simple pen and eraser allowing for drawing and writing only on the whiteboards included in the environment. A warning was included on the poster for the whiteboards because only the pen and eraser is synced, not the board contents itself, this means if you lose connection to the virtual lab the board will be wiped from your perspective.

2.1.7 Organised plates

Three of the tables have plates on them that can attach to the pendulum stand. These plates are organised into Size, Depth, and Density. Each of the plate groups have a sign saying what is varied. This does not mimic the actual lab as they are unorganised in the lab. The idea behind having them organised here is it gives the students a quick idea of the properties they can vary.

2.1.8 The reset button

As shown in figure 7D, there is a large red button and when pressed resets the position and rotation of all items in the lab, this is also known as re-spawning (Which is a common word in digital interactive media like games). This allows students to recover items if you lose them.

2.2 Video Design - Diffraction Grating Spectrometer

The video took under a day to record and the raw video footage came to almost 2 hours in length. Once edited the video was 8 minutes and 54 seconds long.

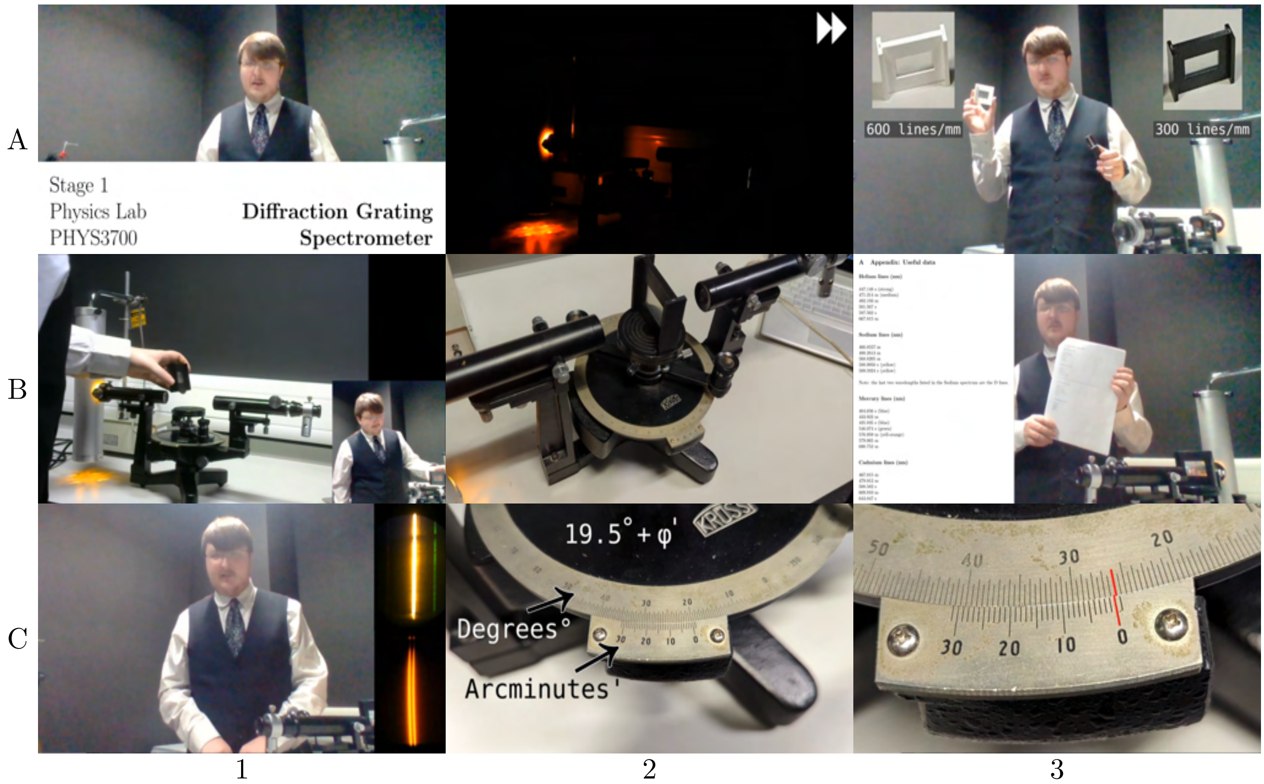

Figure 9: Video Screenshots [28]

2.2.1 Technical Details

The video was recorded using a laptop running Open Broadcaster Software [29]. An arm microphone was used to make sure audio was consistent, and an additional camera was setup on a tripod pointing at the spectrometer as shown in figure 10. The laptop camera was used to record the principle investigator explaining the equipment. A mobile phone was also used to record closeups of the equipment, the table was tapped in frame to sync up all the video footage.

To record the view of the Spectrometer as shown in figure 9.C1, A camera was attached to the Spectrometer using a few clamps to hold the camera to the pivoting arm as shown in figure 11.

Figure 10: The Recording Setup

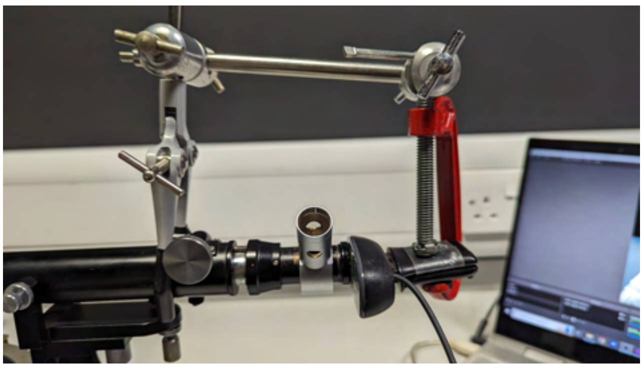

Figure 11: Camera clamped to spectrometer

2.2.2 Suggestions from the demonstrator

Before creating the video, the Diffraction Grating Spectrometer lab's demonstrator was asked what the student's most common mistakes are, and if there is anything in particular they think should be covered in the video.

The demonstrator warned about these points:

- The Vernier scale usually confuses students.
- Students usually forget to take measurements of both the positive and negative angles.
- They usually ask about what they need to record (in this case: angle and colour).
- Sodium's double lines usually confuse students due to the equipment not being able to resolve both lines.

All of the demonstrator's suggestions were covered in the video.

2.2.3 Attempting to keep engagement

To try and avoid the video being boring, a wide variety of camera angles were used, on screen images and text as shown in figure 9. As suggested in this paper on The Video Production of Space, using multiple camera angles helps by orienting the watchers gaze toward different elements [30]. Sections of slow changing parts of the video were sped up for example in figure 9.A2 where the lamp is turning on.

2.2.4 Video Structure

The video is broken up into 21 sections, these are broken down below:

- 00:00 - Intro

  Introduction to the video.
- 00:11 - Startup time

  The gas discharge tube can take time to warm up and begin emitting the correct colour of light.
- 00:42 - Diffraction gratings

  The two different grating options (300 lines/mm and 600 lines/mm) were shown and explained how to tell the difference.
- 01:28 - Where to place the grating

  Described where to place the chosen grating and what angle it should face with respect to the incident light beam.
- 01:58 - Moving the eyepiece

  Explained how to adjust the eyepiece without ruining the calibration.
- 02:45 - How should I hold it?

  Went through the best way to hold the spectrometer to make sure you do not knock it and also ruin the calibration.
- 03:01 - Calibration, What do you expect to see

  Explained that when you look straight down the spectrometer it should have a centred line.
- 03:38 - Calibration, How to Zero the scale

  Sometimes the scale is not zeroed, although the demonstrators zero it, I thought it would be useful to explain how to zero the vernier scale, if needed.
- 04:30 - Dim lines

  The line spectra can be quite dim, especially at higher indexes / angles.
- 04:48 - Reducing error

  As requested by the demonstrator, just a reminder to take measurements for negative angles in addition to positive angles.

- 05:05 - What should I record?

  As requested by the demonstrator, explained that the students need to record Colour and Angle for each spectra line they record.

- 05:19 - Cross-hair

  Showed that there is an optional cross-hair to help line up the spectra lines.

- 05:31 - Lab-script appendix

  Reminded the students that there is a list of known lines in the back of the lab-script, which is extremely useful for doing a sanity check.

- 05:44 - How many orders should I do?

  Recommended only a few orders as any more is just really difficult to see.

- 05:56 - Double lines

  As requested by the demonstrator, Went through how some elements such as Sodium have spectra lines that are very close together, this can make them look like a single line. Student's sometimes then misidentify other spectra lines as the overlapping lines as they expect them to be there.

- 06:27 - Warning: Bright

  Just a safety warning about how the gas discharge tube can be extremely bright, and how the students shouldn't look directly at it.

- 06:36 - Example: How to read the angle 1/4

  This is a simple example on how to read the vernier scale on the spectrometer, in this example the scale lines up perfectly with a number so you do not need to use the vernier scale.

- 06:49 - Example: How to read the angle 2/4 + explanation

  In this example you do need to use the vernier scale, so a detailed explanation on how to read it is given.

- 07:41 - Example: How to read the angle 3/4

  This is a follow up example from the last.

- 08:11 - Example: How to read the angle 4/4

  This is another example similar to the last.

- 08:45 - Ending

  Finally a good luck is given to the students with their up coming labs.

2.3 The Surveys

Qualtrics XM [31] was used to create the surveys as it is the recommended tool for secure surveying by the University Of Kent.

The questionnaires consisted of two parts:

- Experiment Survey
  - Deduction of a Law (Virtual Reality Material)
  - Diffraction Grating Spectrometer (Video Material)
- Comparison Survey

Each Survey attempts to gain insights into if the participant believes the resource was useful to them by asking them questions that could be categorised in the following way (Where X is the preparation material):

- Interest
  - "How interested were you in X experiment?"
- comparative self-rated performance and confidence
  - "How would you rate your performance in the laboratory..."
  - "How confident did you feel overall when entering the laboratory"
- Effectiveness
  - "To what extent did the Virtual Laboratory resemble the In-person Laboratory?"
  - "How many times did you recall elements of X during the lab session?"
- Activeness
  - "Did you take notes while watching the video?"
  - "How tiring was the Virtual Laboratory?"
- Comments

  this was to cover anything else.

The full questionnaire can be found in the Appendix 8.1.
The participants completed the **surveys** in this order:

1. Their first extra preparation material
2. The related Laboratory
3. The related **Experiment Survey**
4. Their second extra preparation material
5. The related Laboratory
6. The related **Experiment Survey** + **Comparison Survey**

3 Method - Running the experiment

3.1 Sign up & Capacity

This study was designed to support up to a maximum of 32 participants. Students from stage one physics were invited to sign up via an online form sent to them via email. Once signed up they were split into two groups and their first two experiments were assigned to Deduction of a Law and Diffraction Grating Spectrometer. The order was reversed for one of the groups. This ensured that all of the participants would do the required experiments for the study in the first half of the term, allowing the other half to be used for analysis and writing up.

3.2 Ethics Considerations

Participation in the study was optional. The participants were given a physical consent form to sign. The participants were anonymised before they took any surveys, this was done by giving them a unique Identification Code. The code was necessary to link their first and second survey together.

In addition none of the raw unprocessed data was shared with anyone related to the marking process. This was to done to ensure that there is no possible way for their performance with the extra preparation materials to effect their grades.

Furthermore the reason Qualtrics XM [31] was used was because it has a reputation of handling survey data very securely.

When running the Virtual Reality Laboratories the participants were offered water and seating as shown in figure 12 in case they were feeling motion sick. Motion sickness, also referred to as Cyber-Sickness in the literature [1].

The ethics proposal for this study were approved by Kent's Centre for the Study of Higher Education (CSHE) ethics committee.

3.3 Scheduling

The part of the study where participants were involved went on for 1 month. As stated before in section 2.3, the order of the participant tasks is stated:

1. Their first extra preparation material **(1st week)**
2. The related Laboratory **(2nd week)**
3. The related Experiment Survey **(2nd week)**
4. Their second extra preparation material **(3rd week)**
5. The related Laboratory **(4th week)**
6. The related Experiment Survey + Comparison Survey **(4th week)**

3.4 Virtual Lab - Deduction of a Law

Participants were invited to a seminar room where all the tables had been pushed to the side, giving a suitable play space. The projector was used to show a live view of what was happening inside the Virtual Lab. This was view useful for taking notes and assisting with any technical issues. Both headsets were setup and ready to go as shown on the left of figure 12, and after each participant had used it, it was wiped down to keep it clean and get it ready for the next participant.

Figure 12: Virtual Reality Room Setup

Moving all the tables and chairs around in the seminar room was difficult and not ideal. Not only was it hard work to move everything about, but moving furniture also ate into the dedicated time slots. One VR session had to be delayed by 10 minutes to finish rearranging the room. Some universities have already addressed this issue with special VR rooms that are always ready, for example the University of Leeds has the Helix Centre [32] and the University of Nottingham has a VR Classroom [33].

3.5 Video - Diffraction Grating Spectrometer

The video was uploaded to Moodle (The Virtual Learning Environment Kent uses [34]) and was then sent via email to participants for them to watch the week before the experiment. It was optional for the participants to watch the video, and all participants who did the video survey watched the video.

4 Results and Discussion

During the virtual reality laboratory sessions observations were written down, these can be seen in table 1. Observations are categorised into how many of the three VR sessions the observation was noted. Observations under “three instances” Occurred in every session.

One Instance	Two Instances	Three Instances
Purple highlighting confused newcomers to VR	Difficulty to write on board	Very fun
Hit each other with virtual objects	Difficulty picking things up	Issue picking things up off floor
Fully ran the experiment	Managed to swing pendulum	Confused about the controls at least once
Confused by respawn button	Team-work	At least one person in group: new to VR
Weren’t afraid to make mistakes	Motion sickness, but went back in	A little confused what to do
Struggle to read lab-script	Fast to learn controls	Struggled to pick up pen
Went around reading posters	Laughed	
	Very confident	
	Liked the plant	
	Thew objects	

Table 1: The frequency of observations written down by the principal investigator during the virtual lab sessions. These observations are the principal investigator’s interpretation of what was happening during the session. Categories: Enjoyment , Positive outcomes , Design related Issues , Understanding related Issues

It is clear from the frequency of observations (table 1) that all of the participants enjoyed the Virtual Reality Laboratory. This can be seen by how all three groups share the “Very fun” observation and two of the groups share “Laughed”.

Out of the participants the majority had never used VR before or have had very limited prior VR experience as shown by figure 13. Although these results show that 5 out of 7 participants had at least used VR before in some capacity. This lines up with the observations (table 1) where one group did not understand how to use the re-spawn button as shown in figure 14. Essentially to use the button the user must put their hand over it and then pull in the trigger on their controller, this is not very clear when you first use VR. This method of using interactables is very common in VR games and experiences, so that explains why the people who had used VR before had no issues.

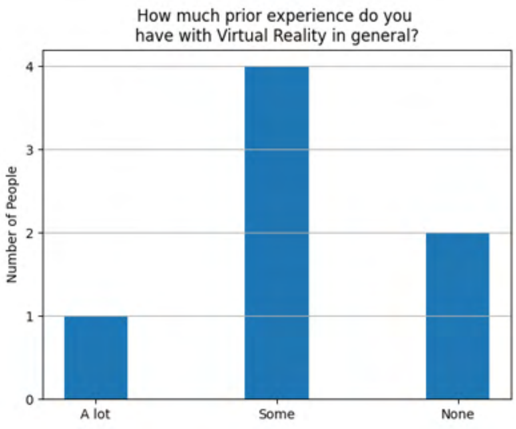

Figure 13: How much prior experience do you have with Virtual Reality in general?

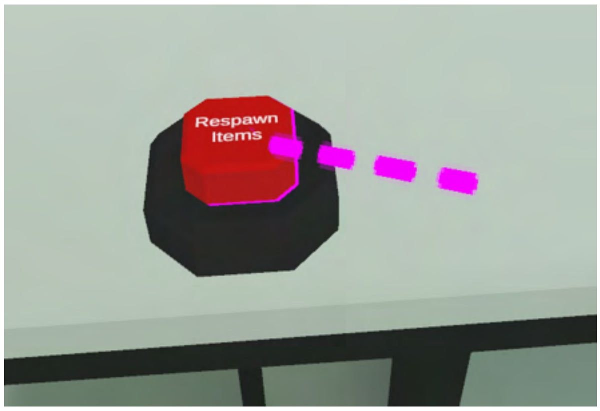

Figure 14: Example of purple highlight to activate button.

All participants had issues with picking up items in some form or another primarily focused around the pen (Figure 15). Almost all participants got used to picking up items very quickly, the main issue occurred when participants accidentally dropped items onto the ground. Trying to pick up items from the ground can be difficult because you either need to lean down to reach the item, or you can use the selection laser as shown in figure 14. The selection laser is not the go to method for most participants as its quite unintuitive if you do not use VR commonly. Imagine the selection laser as a laser pointer that shoots out of your hands at all times, but it only becomes visible if you point at something you can pickup or interact with. Usually its easier just to touch the item with your hand to pick it up.

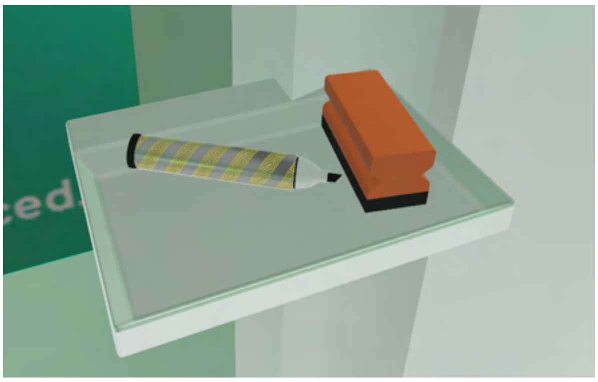

Figure 15: Screenshot of the pen and eraser.

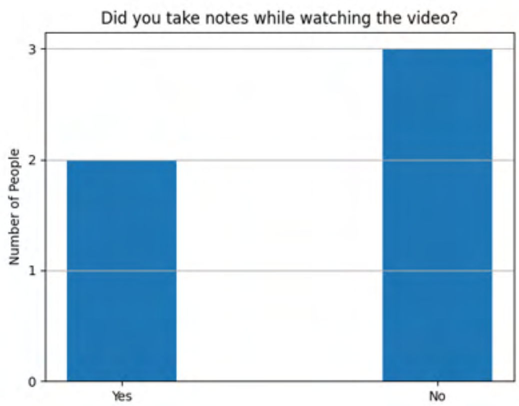

Figure 16: Did you take notes while watching the video?

The Virtual Reality Laboratory was a very active preparation material no matter what the participants did while there were inside of it, but the Video preparation material's "activeness" depended on how much the participants engaged with it directly. For about half of the students it was a very passive experience as shown by figure 16.

Participants unequivocally preferred the Diffraction Grating Spectrometer experiment and preparation Video. When asked to pick which experiment they preferred between Deduction of a Law and Diffraction Grating Spectrometer, all surveyed participants said they preferred Diffraction Grating Spectrometer. Reasons included:

- There was more direct instruction given in the lab-script for Diffraction Grating Spectrometer.

  Participants preferred that they were more guided through the experiment and were not just left to work out what to do. One participant specifically said "There seem to be 2 extremes, either too wordy and confusing or not enough and still confusing.", in this case they were saying that the lab-script given with the Diffraction Grating Spectrometer was too wordy but at least directly guided them through what to do. Whereas the Deduction of a Law lab-script does not give too much direct instruction. This is to be expected because Deduction of a law is more about the students exploring the potential parameter space of the experiment and drawing conclusions, where Diffraction Grating Spectrometer is more about letting the students use equipment they have never used before and confirming that findings line up with what they have learnt in class.

- Exp. F - Diffraction Grating Spectrometer was a more interesting experiment.

  One participant preferred Diffraction Grating Spectrometer simply because they felt that it was more original than Deduction of a Law. They specifically state that it was more interesting as they had never done spectroscopy before. This makes sense as Deduction of a law is in practice a very simple experiment compared to Diffraction Grating Spectrometer, In addition it is likely that students have swung a pendulum before but never used a Spectrometer before.

When asked to pick which preparation material they preferred between the VR lab and the Video, all surveyed participants said that they preferred the Video preparation material. Reasons included:

- "The video was very clear and concise with good examples."

  Participants liked the how the video material gave information and examples, whereas the VR material simply dropped you into the lab and gave participants the opportunity to try things out in advance. The Participants preferred just being given the information over having the opportunity to work through things before the in person lab. The VR lab could of had some kind of guide or tutorial, but that was not implemented due to the time constraints. If a tutorial was implemented for Deduction of a Law, it could have User interfaces (Menus) that guide the students through selecting a plate, hanging it on the pendulum stand, swinging it... etc.

- "The lab for the VR task was not complex enough to require prior practice".

  Participants said that they did not feel they needed the VR environment for a pendulum experiment as its relatively simple. They thought that Diffraction Grating Spectrometer would have been a better fit to be the VR Lab because the VR environment could be good for training them how to use the spectrometer. The reason Diffraction Grating Spectrometer was not selected to be the VR lab was due to the slight amount more complexity. Deduction of a Law was selected to be the VR Lab due to its simplicity and therefore would be ready in the narrow time frame.

- You could watch the video over and over.

  The video can be re-watched and at any time, where the VR lab can only be done at a set time and place, Participants showed that they prefer resources that they have constant access to. In an ideal world there could be VR Headsets always available in a universities Learning Resource Centre, which would resolve this issue.

- The VR Lab caused a headache.

  One participant had a headache after their VR Lab session, they believe it was because the lab environment was too white. The VR Lab is quite bright in its design, It is also quite possible that their headache could have been caused by Cyber-sickness (Motion sickness) and then the brightness made it feel worse. It is certainly not good if the VR Lab gives participants a headache as that distracts the participant from the material in the VR lab.

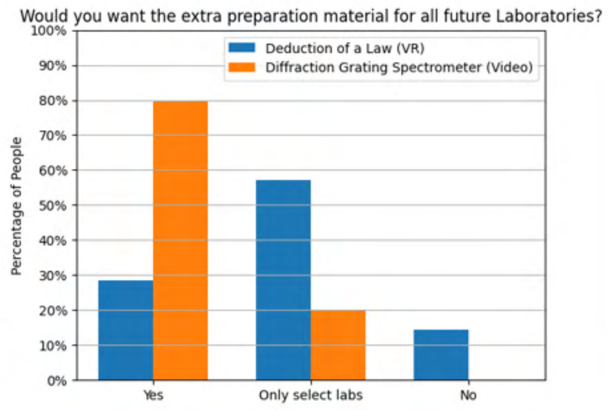

Figure 17: Would you want the extra preparation material for all future Laboratories?

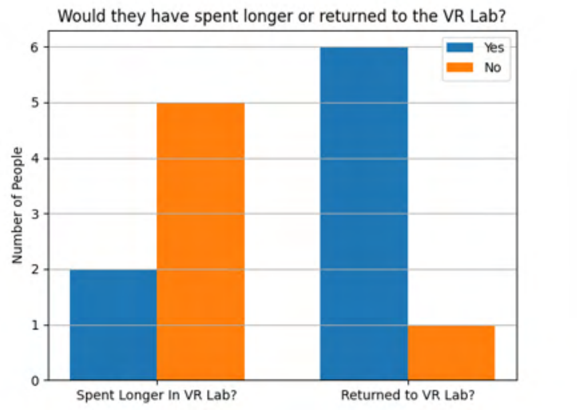

Figure 18: Would they have spent longer or returned to the VR Lab?

Participants were asked if they felt they wanted more time in the VR lab, most of the participants said they felt that the VR session was the ideal length of time (Figure 18). This makes sense because during the VR sessions far fewer participants showed up than expected so the participants were allowed to stay in the VR session until they had enough. Therefore it makes sense that they all thought it was the ideal length of time because they got to pick.

They were also asked if they would have returned to the VR Lab if it was always available, for example if there was some kind of VR lab location that they could always go to. Most participants said that they would have returned to the VR lab if it was always available (Figure 18). This lines up with a comment earlier for the question "which preparation material they preferred between the VR lab and the Video" where one participant said the video was better because you could watch the video over and over. If there was a space where students could go to use VR headsets it would resolve this and it appears that students would want that option to be available.

Participants were asked if they would want the VR labs for all future labs, the majority said only for select labs (Figure 17). Examples of select labs include:

- "labs that require just measurements"

  Participants said that they did not really want to do any theory or mathematical work within the virtual lab. This makes sense this VR Lab was not really ideal for doing maths as it did not have any kind of calculator within it, although it did have a whiteboard it would have been impractical to write out long calculations within VR. This is mainly because the whiteboard was difficult to use especially for participants who were not used to VR. This is covered in more detail in the Reflections of design considerations (Section 4.1.5).

- "Ones with equipment not used before"

  Participants said that labs with equipment they are unfamiliar with would be better for Virtual Reality Labs. One example that was given was "Diffraction grating spectroscopy" because of the spectrometer that participants had never used before. The followed up by saying that "it would be very tedious and unnecessary if it was for all labs." referring the virtual reality lab.

- "Ones that are simple to follow"

  One participant said that Virtual Reality labs are better for labs that are simple to follow or easier to make visible progress. This could be achieved by for all labs if there were some sort of guide or tutorial which clearly gave the student goals to achieve within the virtual lab.

When participants were asked if they would want Videos for all future labs the majority said unconditional Yes (Figure 17). The participants who chose Only select labs did not give any reasons as to why. Speculating for a moment based on the responses for the VR Labs: It is possible that they thought that some laboratories are quite simple to follow and do not need any additional video material.

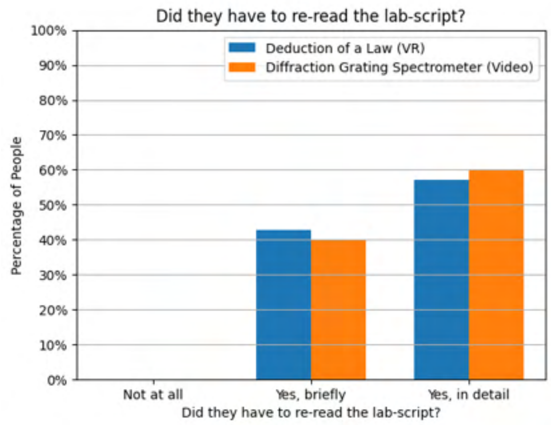

Figure 19: Did they have to re-read the lab-script?

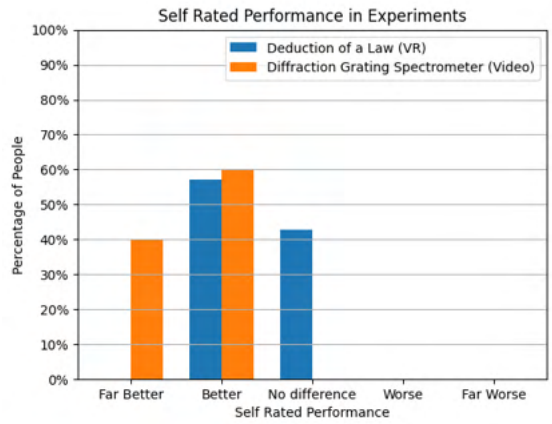

Figure 20: Self Rated Performance in Experiments

Participants were asked if they had to re-read the lab-script when they finally got into the real laboratory, It seems that the preparation material type had no effect on participants needing to re-read the material as shown in figure 19. Although on average it seems that most participants have to re-read the lab-script in detail when they get into the lab. This indicates that neither the video or VR lab directly told the students what to do, which is ideal as the design of both preparation materials was to help the students understand the lab-scripts better, although if participants had only briefly read the script or not at all before the pre-lab material that would explain why the participants would need to read the lab-script in detail when entering the real lab.

When participants were asked to rate their own performance in each of the experiments after engaging with the pre-lab materials, on average they rated that they think they performed better in Diffraction Grating Spectrometer after watching the video compared to Deduction of a Law after partaking in the virtual lab as shown in figure 20. This suggests that all of the participants felt the video helped them in the real laboratory in some way. Meanwhile some participants felt that the Virtual realty lab helped or did not change anything for them. No participants felt like either method was a detriment. Its unclear how the video and VR methods in different kinds of labs would effect this, as some participants did feel that the VR lab was used in the wrong kind of experiment, This could explain why some participants felt like the VR Lab made no difference to their performance.

In addition participants were asked to rate their own confidence in the real labs after engaging with the pre-lab materials, all participants said that they felt more confident after engaging with the video material, whereas almost all students reported no change of confidence after the VR-lab. This suggests that the participants felt like the video prepared them better for the lab.

Finally the participants were asked if they had any final comments for anything related to this study. One participant mentioned how they were surprised that they did not experience any cyber/motion sickness when they usually do in a car. This was quite surprising as ConVRse does not have any systems to reduce cyber sickness, it is not clear why they did not feel sick when they expected to but either way it was a good thing. Although there was another participant who did get cyber sickness but it is unclear if they usually get cyber/motion sick.

Another comment said that the VR did not add anything to the lab and they would have preferred a pre-recorded video. This makes sense because during most observations participants did not really do much of the experiment at all, this is likely because there was no guidance or tutorial. Participants mostly just looked at the different equipment in the virtual lab, this prepared them for what was going to be in the lab but a video could have also just shown them an equipment list.

A few participants said that the video was very helpful because it summarised the long winded lab-script, One specifically noted that the lab-script did not mention how to use the Goniometer/vernier scale. This seems to be true although there is some information on the goniometer in a highlighted box labelled “Hints and Tips” in the lab-script. It seems that participants found a demonstration of how to use the goniometer very helpful.

Lastly, One comment read “Lab-scripts are too vague, it makes it really hard for me to actually do the lab which stresses me out.”. Throughout all the comments collected participants had complaints about the way lab-scripts are written. This study did not focus on lab-scripts but it seems they may need further research. These feelings towards lab-scripts could be because of the nature of them, they are not designed to give students answered but instead to guide them to interesting findings. If improperly designed it could leave students lost and/or having to make jumps to get to each point, in some cases the lab-script is purposely designed that way, for example Deduction of a law does not give the students too much to work off and expects students to experiment and come to their own conclusions on what effects the time period. Although educators likely noticed this difficulty as there is a complimentary hints document with Deduction of a law which is unusual.

4.1 Reflections on design considerations

4.1.1 Object placement

Placing the pendulum and stopwatch on the same table but just far away that they need a pair to operate worked very well at getting the participant pairs to work together. Usually one of the pair would coordinate the other to start and stop the timer, this was seen in at least 2 of the 3 groups (Table 1). These observations were very promising as this is exactly the sort of teamwork that is required for the real lab as well. It can be seen that the placement improved the participant pair dynamic as when observing, one participant would always try to operate it alone, realise that they cannot and then call over the other participant.

4.1.2 Posters

The posters were effective in at least one instance, this was shown when a participant was observed going around reading them (Table 1). It is likely that other participants did look at them but it was not noticed. For example all students read and paid close attention to the controls poster, although that was because it was necessary for moving and interacting with the virtual environment. There was also another instance of a participant explaining to another how to use the virtual vernier calipers, although it was not clear if they worked it out themselves or read the sign.

4.1.3 The plant

Participants were intrigued by the plant, they seemed to pick it up and throw it around the virtual lab. At the time participants commented that the reason they were interested in it was because it seemed unusual to have a plant in a physics laboratory. This was good because a lot of the participants were drawn to it but wanted to pick it up, a few failed to pick it up a few times but because of its big size it was easy for them to grab it and try again.

4.1.4 Lab-script

Participants did look over the lab-script, but most of them were still confused what they were meant to be doing in the virtual lab after looking at it. One participant pretended to playfully hit their partner with the lab-script (The lab-script has no colliders therefore it passed through them like they were a ghost), they were both laughing as they did this. Most participants read the lab-script quite seriously, this was shown by them going quite quiet and focused when reading it, although all that did read it mostly skimmed through it.

One group held the lab-script up to the camera that was projected onto the screen (usually for the principle investigator to take notes of what was happening in the VR Lab) and another participant who was not in the VR lab started to read it for them. It was surprising to see participants working together inside and out of the VR lab as this was a complaint in another Virtual Reality Education paper had mentioned [10].

4.1.5 The Whiteboard

Participants very intuitively attempted to write on the whiteboard by picking up the pen and trying to drag it on it. Although most participants struggled due to the whiteboard not having a collider, therefore the pen would just go straight through. This confused students and caused it to take longer for them to work out how to write anything.

In addition participants very commonly dropped the pen and eraser. Due to how small they are, the participants really struggle to pick them back up. For most participants a lot of time was spent trying to work out how to hold the pen correctly without dropping it.

4.1.6 Organised plates

One of the staff related to Deduction of a Law said that once they had organised all the plates into categories, but after one lab session it was a mess again. This was similar in the Virtual Reality lab, participants would mess up the organisation of the plates, but due to it being a Virtual Lab it did not matter.

If the VR lab was modified to have objectives/tasks it could be a good idea to guide the students to tidy up after themselves, this could lead to the students changing their behaviour in the real lab, hopefully leading to the staff not feeling defeated when trying to keep the equipment organised.

4.1.7 The reset button

Participants seemed to get confused in two ways by the reset button:

1. The reset button does not behave like how many participants expected, they expected the button to be pressed physically, instead the way it is used is you point at it so it turns purple and then click to "use" it.

   One thing to note is participants with prior Virtual Reality experience did not find this unusual.

2. There was not much feedback when they used it, therefore it was not clear that it had done anything. Participants would press it multiple times and then look around the virtual room confused wondering what it did or if they even pressed it at all.

   This is likely because not all participants were familiar with the idea of re-spawning especially because the world re-spawn is usually used in Video Game Terminology.

4.2 Survey Participation

This study was only able to get 9 participants to sign up in the end, far less than planned. This was primarily because of ethics approval being quite late meaning the potential participant pool was only advertised to about a week before the start of the study. Although with those time constraints in mind, 9 participants signing up is quite good.

Of those 9 participants only 7 took part in the Virtual Reality Sessions, but all 7 filled out the VR Survey. In addition, only 5 took part in the Video Session and filled out the survey (More participants could have watched the video and not filled out the survey but that information is not known).

It is not clear why the video participation was lower than the VR participation, This could have been because of a novelty effect where the hype around Virtual Reality made the participants want to give their feedback about it.

5 Conclusion

Participants preferred the Video preparation material over the VR preparation material, this was primarily because the video gives far more guidance on what to do compared to the VR lab. Although this result does not mean that using social virtual reality is a lost cause, this result shows that virtual reality labs without guidance isn't perceived as useful as a video. However it should be noted that participants thought that Deduction of a Law was a fundamentally simpler experiment to run compared to Diffraction Grating Spectrometer, therefore is is possible this could lead participants to feel that the video was more useful.

Social virtual reality still shows promise in the teaching of physics shown by the levels of enjoyment that were seen in this study (Table 1), High enjoyment can lead to intrinsic motivation which is an important factor for learning in VR environments according to the CAMIL [21].

A limitation of this study is fewer participants took part in the study than was anticipated and those who took part are likely a subset of students from stage one who engage with lots of extracurricular activities. Keep in mind it is unclear due to the small participant turn out, how much can be reasonably extrapolated from the results. If a future study like this is run one method to try and increase participant count would be to allow participants from many more year groups, or to integrate these materials into their course as a required part (Although this is only a reasonable solution for multi-year studies).

The University of Kent does not have any dedicated virtual reality spaces for using VR, which caused a lot of difficulties for the Principle Investigator. They had to rearrange furniture in seminar rooms for the VR sessions, this is detrimental to future VR studies (especially for Investigators who may struggle with rearranging rooms). Furthermore if there was a dedicated space for VR it means that students could book access and enter the virtual labs whenever they would like, which is something the study identified that some participants wished they could do (Figure 18). Other universities have setup dedicated VR spaces for the purposes of making research easier and giving the students an area to easily access VR (Leeds [32], Nottingham [33]).

This study appeared to be able to solve an issue that presented in the VR Geography Study [10]. In that paper there is a student experience empathy map for their VR sessions, their participants complained about it being a "Solo experience". Naturally that was not a complaint from the participants of this study. Although both studies find some students suffer from cyber-sickness and struggle with controls.

The effort and time required to make a VR Lab completely out weight the return on perceived learning outcomes (very low due to lack of guidance), it took weeks to create the virtual lab although this was because it was fully custom, if there were pre-made assets that would speed up the process significantly. On the other hand the video material was perceived as useful to all participants and the time required to make it was about 2-3 days (1 day to record, 2 days to edit), the amount of time required to make these videos while keeping them engaging with multiple camera angles and diagrams depends on the skill-set of the educator making the video.

If this study had more time it could have been insightful to see the students grades for these labs compared to the average grade of the year. It would be possible to investigate if what the participants thought was helpful is actually helpful. Although it's possible that those insights would be meaningless without mandatory participation because more outgoing students are likely to sign up to extracurricular activities (Which is what happened in this study shown in table 1 by confidence. Participation bias effects many fields of research [35], there does not appear to be any literature going into this exact form of participation bias).

A few of the participants negatively commented on the lab-scripts complaining that they are either too vague or too complicated. This was one of the reasons participants liked the video because they felt like it cleared up the confusion they had from the lab-script.

This studies results were inconclusive for if more active learning materials are better for learning, this is because it was difficult to compare both the VR lab and video materials fairly. Otherwise this study would suggest that more passive materials are better which is against the literature [17].

It was shown that careful design in the arrangement of objects and systems within the virtual environment can lead to desired learning behaviours. For example when the timer and pendulum were placed near each other but just far enough away that they both cannot be operated by one person, it led to participants calling each other over for help encouraging teamwork (Section 4.1.1).

Overall participants were more confident and had higher interest in labs that they felt better prepared for, in the case of this study participants felt the video better prepared them for their laboratory. Whereas the VR experience was more fun and silly but did not significantly effect their confidence and interest in the respective lab. It must be noted that both laboratories were quite different and if there was more time it would have been better to have produced a video and a VR experience for both labs to better compare them, which would reduce the uncertainty of this result.

6 Future Research

FURTHER Research is needed to investigate what needs to be done to make virtual reality a useful learning resource in the teaching of physics and education more generally. A study should investigate what type of VR environments students feel lead to better learning outcomes, this study has suggested that unguided labs although enjoyable are not very effective but more research needs to be done to be conclusive. Examples of other types of environments include:

- Guided labs

  Virtual Labs with instructions or some kind of tutorial or AI assistant.

- Interactive classrooms

  Sort of like a PowerPoint presentation but as a space. There could be transitions and animations related to objects in the VR environment.

- Exhibits

  Museum styled environments where the student can walk around to attractions similar to the one shown in figure 1.

- Trips/Tours

  The ability to go anywhere with an instructor and learn about it, for example going to CERN as shown in figure 2.

- Learning games

  Gamification of physics learning material in the VR space.

It was also not possible to deduce through surveys alone if the participants had gained any useful behaviours (like teamwork as described in section 4.1.1) from the VR environment. Future research should consider ways of measuring this for example by also taking notes in the real labs.

The video preparation material was shown to be perceived as effective in this study but required skills in video editing to produce a high quality video. It would be insightful to investigate if this use of high quality video editing is required for students to find it effective, directly comparing a video similar to this study [28] against a more traditional visualiser or presentation styled video. If traditional videos are just as effective it would be better to use them as they take a lot less time to produce.

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8 Appendix

8.1 Questionnaire

PHYS7000 Questions

"Your responses are anonymous, and no academics involved in your labs or marking will have access to your responses. Therefore, your responses to this survey will not affect your grades in any way."

The participants will complete tasks in this order:

- Their first extra preparation material
- The related Laboratory
- The related Survey A
- Their second extra preparation material
- The related Laboratory
- The related Survey A + Survey B

Survey A – After both Experiments

Virtual Reality – Pendulum – Deduction of a law

Definitions

- Virtual Laboratory – The virtual reality recreation of the laboratory experiment.
- In-person Laboratory – The actual experiment conducted for PHYS3700 In Laboratory 3.

1. How interested were you in this experiment?
    a. Very Interested
    b. Interested
    c. Slightly Interested
    d. Not Interested
2. How much prior experience do you have with Virtual Reality in general?
    a. A lot, I use it frequently.
    b. Some, I have used it before.
    c. None, I have no prior experience.
3. How would you rate your performance in the In-person Laboratory after engaging with the Virtual Laboratory compared to a previous laboratory where you only had access to the lab-script?
    a. Far Better
    b. Better
    c. No difference
    d. Worse
    e. Far worse
4. How confident did you feel overall when entering the In-person Laboratory compared to a previous laboratory where you only had access to the lab-script?
    a. More confident
    b. No Change
    c. Less confident
5. When you entered the In-person Laboratory did you have to re-read the lab-script?
    a. Yes, in detail.
    b. Yes, briefly
    c. Not at all
6. To what extent did the Virtual Laboratory resemble the In-person Laboratory?
    a. A lot
    b. A little
    c. Not really
    d. Not at all
7. How tiring was the Virtual Laboratory?

    a. Exhausting
    b. Tiring
    c. A little tiring
    d. Not at all
8. How many times did you recall elements of the Virtual Laboratory during the In-person Laboratory session?
    a. More than Once
    b. Once
    c. None
9. When in the Virtual Laboratory, To what extent did you complete the virtual laboratory?
    a. [Text Input]
10. If possible, would you want Virtual Laboratories for all future In-person Laboratories?
    a. Yes
    b. Only select labs.
    c. No
11. [IF only select labs] If you selected only select labs, off the top of your head which labs and why?
    a. [Text input]
12. How would you rate the clarity of instructions provided in the Virtual Laboratory?
    a. Very Clear
    b. Clear
    c. Neutral
    d. Unclear
    e. Very Unclear
13. When did you read the lab-script?
    a. Before the virtual reality lab
    b. After the virtual reality lab but before the in-person lab
    c. Both
    d. Neither
14. Would you have spent longer in the Virtual Laboratory if you could?
    a. Yes, more time
    b. No, it was an ideal length
    c. No, less time
15. Would you have returned to the Virtual Laboratory if it was always available?
    a. Yes
    b. No
16. Is there anything else you would like to say about the Virtual Laboratory?
    a. [Text Input]

Video – Spectroscopy – Diffraction Grating Spectrometer

1. How interested were you in this experiment?
    a. Very Interested
    b. Interested
    c. Slightly Interested
    d. Not Interested
2. Did you watch the video?
    a. Yes
    b. No
3. [Required Video Watch] How would you rate your performance in the laboratory after engaging with the Video Recording compared to a previous laboratory where you only had access to the lab-script?
    a. Far Better
    b. Better

    c. No difference
    d. Worse
    e. Far worse
4. [Required Video Watch] How confident did you feel overall when entering the laboratory compared to a previous laboratory where you only had access to the lab-script?
    a. More confident
    b. No Change
    c. Less confident
5. When you entered the actual lab did you have to re-read the lab-script?
    a. Yes, in detail.
    b. Yes, briefly
    c. Not at all
6. [Required Video Watch] Did you take notes while watching the video?
    a. Yes
    b. No
7. [Required Video Watch] Did you watch the video more than once?
    a. Yes, More than twice
    b. Yes, Twice
    c. No, only once
8. [Required Video Watch] How many times did you recall elements of the video during the lab session?
    a. More than Once
    b. Once
    c. None
9. [Required Video Watch] Did you watch it at double speed or faster?
    a. Regular
    b. Double
    c. Faster
10. If possible, would you want Video preparation materials for all future labs?
    a. Yes
    b. Only select labs.
    c. No
11. [IF only select labs] If you selected only select labs, off the top of your head which labs and why?
    a. [Text input]
12. [Required Video Watch] How would you rate the clarity of instructions provided in the Video Recording of the Laboratory?
    a. Very Clear
    b. Clear
    c. Neutral
    d. Unclear
    e. Very Unclear
13. When did you read the lab-script?
    a. Before the virtual reality lab
    b. After the virtual reality lab but before the in-person lab
    c. Both
    d. Neither
14. Is there anything else you would like to say about the video preparational material?
    a. [Text Input]

Survey B – After 2nd Experiment

1. Which extra preparation material did you prefer?
    a. Virtual Reality Laboratory
    b. Video Recording of Laboratory

2. Please explain why you preferred that material.
    a. [Text input]
3. Which experiment did you find more interesting?
    a. Spectroscopy – Diffraction Grating Spectrometer
    b. Pendulum – Deduction of a law
4. Please explain why you preferred that experiment.
    a. [Text input]
5. Final Question: Is there anything else you would like to say about any of the preparational materials (Lab-script, Virtual Reality Lab, Video) or either laboratory?

8.2 Error in the Diffraction Grating Spectrometer Survey

A minor error was noticed in question 13 of the Video – Diffraction Grating Spectrometer Survey, unfortunately this was only noticed during data processing.

> **When did you read the lab-script?**
>
> a. Before the virtual reality lab *[Error here]*
>
> b. After the virtual reality lab but before the in-person lab *[Error here]*
>
> c. Both
>
> d. Neither

Figure 21: The error in question 13 of the Video – Diffraction Grating Spectrometer Survey

The question is meant to be asking about the video pre-laboratory preparation material, but instead asks about the Virtual Reality pre-laboratory preparation material. It is possible that the participants noticed this and answered it as intended but due to the uncertainty the answers to this question were ignored as its unclear if the results for it are meaningful.