From Picks to Pixels: An Exploration of Virtual Reality in Geoscience Education

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Figure 1: Our system for virtually teaching undergraduate geology students practical skills to prepare them for real-world field work. The system takes students through a series of lessons consisting of 360° video, virtual tools, and photogrammetry scans of geological features.

Abstract

In this work we present our system for teaching practical geology field skills through a combination of 360° video, photogrammetry, and virtual content. The system was evaluated with first- and second-year undergraduate geoscience students to determine if it was effective in teaching practical skills that could be transferred to the real world. Second-year students who had performed the task before saw a significant improvement in their abilities, however this improvement was absent in the first-year students, suggesting the tool may be more effective for revision rather than first-time learning. We discuss these findings and their implications for future virtual training tools, as well as the challenges in developing and deploying such systems in a university environment.

Index Terms: Immersive Education, Virtual Reality

1 Introduction

Recent advances in the capability and availability of Virtual Reality (VR) devices have given rise to a significant growth in VR research and the development of applications for virtual education. A wide range of age groups and abilities have been explored as potential beneficiaries of this technology, ranging from primary and secondary education [7, 2, 10, 27] to tertiary education [6, 19, 41, 40] and even advanced medical training [24, 11, 25].

In this paper, we explore how virtual reality can be further applied to teaching practical skills in tertiary geoscience education. This is a discipline uniquely positioned to benefit from VR research due to a heavy reliance on practical fieldwork which is often disrupted by factors such as poor weather, physical disabilities, and travel restrictions. We have developed a VR application that aims to replicate the experience of working in the field when physical access isn't possible, allowing students to learn and revise crucial field skills without regard to these uncontrollable disruptions. We

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present the results of two successful in-class tests of our system with a undergraduate geoscience students, proving VR's potential for replicating these types of physical lessons.

2 Related Work

Research has shown that virtual reality (VR) can be an effective teaching tool in a wide variety of scenarios [18, 34, 13, 33, 39]. The high immersion inherent in VR technologies can lead to higher student engagement with lessons than traditional forms of learning [15], creating a sense of concentrated focus and enjoyment by immersing them within the educational content [5]. This engagement and sense of immersion can lead to equal or better learning outcomes than traditional teaching methods [32] by increasing knowledge retention, satisfaction, and self-efficacy [38], and resulting in higher procedural memory retention than non-immersive tools [26]. The use of VR in the classroom may also lead to higher academic achievement by making learning fun [42], which in turn may make students more willing to use these tools in the future [29].

VR is particularly suited to educational content with a practical component as virtual simulations allow for free motion and spatial metaphors in contexts such as field trips, simulated laboratories, and virtual dissections [34]. Simulations also allow for tasks to be easily repeated with greater flexibility in the variation of learning scenarios, for example, by presenting tasks within different environments [24] which is difficult to replicate in a physical environment. This flexibility also facilitates training within scenarios that might otherwise be dangerous or difficult to access in reality [1, 43]; this makes disciplines such as geosciences particularly suited to virtual replication due to a heavy reliance on practical fieldwork [16].

2.1 Virtual Reality in Geosciences

Several projects have begun to investigate what a virtual geoscience teaching tool might look like. Muir et al. explored the use of VR to visualise complex rock structures [35], providing a more engaging and spatially intuitive representation of these structures than possible with field observation. Gallagher et al. [19] improved upon this foundation by adding an interactive lesson to the visualisation, though interactions with the environment itself were fairly limited.

Turkay et al. [41] investigated the use of VR beyond a terrestrial setting by simulating data collection on the surface of Mars, tasking users with differentiating between two different types of rock. While this showed the potential of VR for simulating scenarios impossible in real life, the actual interactions with the virtual surroundings were still kept to a minimum with a focus on visual rather than physical interaction. Several similar systems have recently been developed to virtually simulate field experiences [22] or visualise geological data [17], however these lack an evaluation of their effectiveness as a teaching tool.

In response to the COVID-19 pandemic, Gregory et al. [12] developed a series of geology learning modules combining physical materials and virtual simulations. Students could interact with the virtual environment, though this was done through a traditional desktop display. Recent years have seen the introduction of several similar desktop-based simulations of field work [21, 9, 20]; these were well-received by students, who suggested that the use of these tools was effective for learning, however this was measured through self-reported data rather than more objective proficiency tests.

Another field that has seen explorations into virtual learning is archaeology [37], which faces similar challenges and opportunities to geoscience education due to a focus on physical manipulations and field work [3] For example, Yi et al. [44] developed a VR simulation for practicing excavation techniques, however its effectiveness as a teaching tool were not evaluated. Derudas and Berggren [14] developed a similar but non-immersive tool for analysing excavation sites; this was successfully tested by students

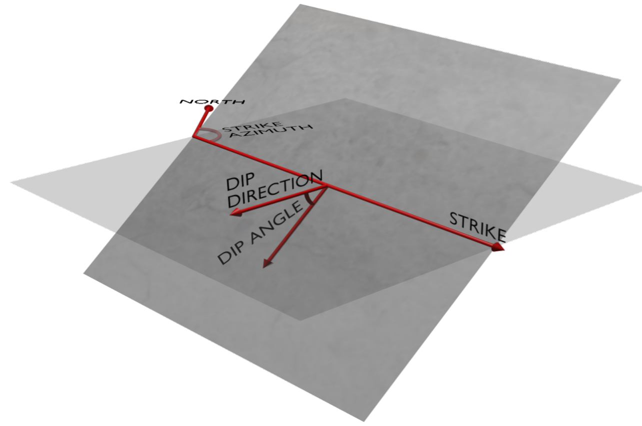

Figure 2: A graphical representation of the strike and dip of a bedding plane. A plane's strike runs horizontally along a surface and is measured in degrees clockwise from north, while its dip runs down its surface perpendicular to strike and is measured in degrees relative to the horizontal dip direction.

and integrated into their field work, however it is not clear what effect its use had on the quality of their education compared to more traditional tools. Di Giuseppantonio Di Franco et al. [36] found that their desktop-based 3D Virtual Dig software successfully taught students concepts related to excavations, however this focused on theory rather than practical skills.

While these systems are promising, there has yet to be a comprehensive exploration of how virtual reality can be used to facilitate meaningful interactions with the geological features being studied. Existing work also tends to focus solely on theoretical concepts, and those with a practical or teaching element have not considered how these skills might transfer to the real world.

3 System Overview

Our system was designed to teach undergraduate geoscience students how to measure the strike and dip of a bedding plane using a geological compass, which is a fundamental skill taught in any geoscience course and used for a variety of purposes in the field. A bedding plane is a depositional surface within a sedimentary rock, with its dip being the angle at which it intersects with an imaginary horizontal plane and its strike being the azimuth of this line of intersection relative to north; a graphical representation of these concepts can be seen in Figure 2.

The development process of the system involved user requirement gathering through interviews with undergraduate, postgraduate students and members of staff, observational studies of current geoscience teaching practices and iterative testing with a subgroup of stakeholders.

The application was developed using the Unity game engine and the XR Interaction Toolkit to allow compatibility with a range of XR devices. We used a Meta Quest 2 in our tests as we wanted to ensure that our solution would be effective on accessible low-end hardware.

Based on previous studies we assumed that students would have limited experience with virtual reality and so the lesson started with a short tutorial covering the basics of how to interact within a virtual environment. Concepts were covered such as how to look around, how to navigate the user interface, and how to interact with the virtual objects around them. This was delivered through a series of short 360° videos introducing each concept followed by a short interactive activity where students would demonstrate their understanding of that concept, for example by following the speaker around the room with their gaze.

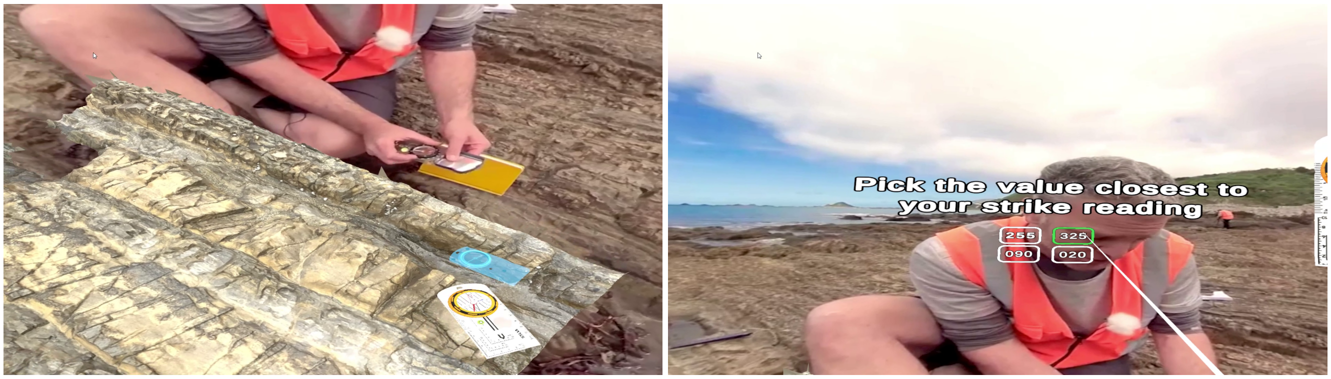

Figure 3: (Left): Students are shown the correct position to place their compass in in order to measure the strike of a virtual bedding plane. (Right): The student is presented with a multichoice question asking the strike of the virtual bedding plane.

After completing the tutorial, students were placed into the main strike and dip tutorial, which was again delivered through a combination of 360° video and virtual 3D content. The lesson consisted of a series of steps where 360° video of a demonstrator showed how to perform a certain action, followed by an interactive task where students had to replicate what they had just been shown using a virtual compass and a 3D scan of the bedding plane created using photogrammetry, as demonstrated in Figure 3. The system also quizzed students at several points to ensure they were performing the measurements correctly.

The lesson was structured as follows:

1. A 360° video introduced students to the concept of strike and dip.

2. Students were instructed on how to pick up and interact with their virtual compass, including rotating the large dial on its face.

3. The instructor demonstrated how to align a compass against a bedding plane in order to measure its strike. Students could not proceed until their virtual compass was correctly positioned against a 3D recreation of the bedding plane.

4. Students were shown how to rotate the compass dial into the correct position to take a measurement, with the red magnetic needle inside a large red outline on the dial face. This had to be done correctly before proceeding.

5. The instructor demonstrated how to take a strike reading from the compass now that it is in position. Students were presented with a multi-choice question asking what the strike of their virtual bedding plane was and could not proceed until they gave the correct answer.

6. Students were shown how to read the plane's dip direction, or the compass direction in which the plane slopes downwards. Once again, students had to answer a multi-choice question about the dip direction of their own surface before proceeding.

7. Students were guided in how to rotate the compass dial to the correct position for measuring dip angle, and to place the edge of the compass baseplate along the line of dip on the bed surface; this had to be done correctly before proceeding.

8. Finally, the students were shown how to take the dip measurement from their compass, and were asked the dip angle of their own surface through another multi-choice question.

The entire lesson took roughly fifteen minutes to complete.

4 Evaluation One

To evaluate the effectiveness of our virtual teaching tool we conducted a user study on a class of second year geoscience students studying in the School of Geography, Environment and Earth Sciences at Te Herenga Waka - Victoria University of Wellington, New Zealand. This took place within their regularly scheduled lab hours, though participation was not required as part of the course. Ethical approval was granted by Te Herenga Waka - Victoria University of Wellington's Human Ethics Committee (#HE031038). Signed consent was obtained from all participants before data collection began.

In conducting this research we had the following hypotheses:

- (H1): Students would score significantly higher in the real-world strike and dip proficiency test after using the virtual training tool than they did beforehand.

- (H2): Students would complete the real-world proficiency test significantly faster after using the virtual training tool than they did beforehand.

25 students were recruited between the ages of 19 and 25 ($M = 20.24$, $SD = 1.75$), of which 12 were male and 13 were female. Only three had never used virtual reality, and the remaining 22 used VR no more than once per year.

4.1 Study Design and Procedure

After signing a consent form and completing a short demographics questionnaire, students were first asked to measure strike and dip using a real compass and dipping surface. This was used to establish a baseline of their current familiarity with the task. Each student was assigned a score out of 10 based on their demonstrated knowledge and accuracy, and were also timed to determine how long the exercise took them. The study facilitator did not provide any assistance during this task and marked students based on the first answer they gave for each measurement, no matter how incorrect. See the supplementary material for the checklist used for this evaluation.

Students were then asked to complete the virtual strike and dip lesson outlined in section 3. The study facilitator helped them put the headset on correctly but gave no assistance beyond that as an introduction to the controls was included as part of the virtual lesson. This took roughly fifteen minutes per student, with three students completing the lesson simultaneously but independently. After completing the tutorial, students completed a series of questionnaires to evaluate their experience using the system including the Simulator Sickness Questionnaire (SSQ) [28], the System Usability Scale (SUS) [8], and the NASA Task Load Index (TLX) [23].

Space was left after each questionnaire so that students could provide free-form comments to justify the scores they gave.

Students then repeated the strike and dip proficiency test using a real compass and dipping surface. The procedure for this was the same as for before the virtual lesson: students were assigned a score out of ten based on their accuracy and demonstrated knowledge, and were timed to determine how long the measurement took to take.

Finally, students were interviewed to gather qualitative feedback about their experience using the system. These interviews were either conducted one-or-one or in small groups of two or three depending on how many students completed the virtual tutorial simultaneously. Students were asked about how they felt using the system, how they could see it fit into their education, possible areas of improvement, and other exercises that the technology could be applied to.

5 Evaluation One - Results

All quantitative data was checked for normality using a Shapiro-Wilk test. Normally distributed non-ordinal data was compared to the midpoint using paired t-tests ($N = 25$, $\alpha = 0.05$), while non-parametric and non-ordinal data such as Likert scale responses were compared using Wilcoxon rank-sum tests.

5.0.1 Real-World Proficiency Results

When asked to demonstrate their existing proficiency in measuring strike and dip before the virtual lesson, students scored a mean of 7.90/10 (SD=2.80), with this score increasing to a mean of 9.62/10 after the lesson (SD=0.68) (see Fig. 4. A Wilcoxon rank-sum test revealed this score increase to be statistically significant ($p < 0.01$, $r = 0.60$), thus supporting our first hypothesis.

The lowest score before the test was 2/10 which was achieved by two of our students, with the highest being a perfect 10/10 as achieved by 10 students. After testing, the lowest score increased to 8/10, as achieved by three students, with 18 achieving a perfect score. Only one student scored lower after the tutorial than before, dropping from a 9.5/10 to a 9/10.

Measuring the strike and dip of the real-world surface took students 1m 46s on average before completing the virtual tutorial ($SD = 34s$). After completing the tutorial this time reduced to an average of 1m 21s ($SD = 29s$), with a Wilcoxon rank-sum test revealing this difference to also be highly statistically significant ($p = 0 < 0.0001$, $r = 0.84$), thus supporting our second hypothesis.

Only three students were slower in completing the measurement after the tutorial, and this was only by one, three, and four seconds in each case. All three scored at least 9.5/10 in the pre-experiment test, indicating that they were already comfortable in completing the measurement.

5.0.2 Questionnaire Results

Perceived workload was rated fairly low across participants, with a mean raw TLX score of 27.44/100 ($SD = 15.44$). As seen in Figure 5, students indicated that the task required relatively high mental workload ($M = 3.24$, $SD = 1.30$) and effort ($M = 2.96$, $SD = 1.31$), suggesting that they found the task challenging. Self-reported performance was also rated low across the board ($M = 3.24$, $SD = 1.70$), indicating that students weren't confident in their results even if they all scored highly in the post-experiment test. Ten participants cited the controls as the cause of their difficulties in their open questionnaire responses, while nine blamed the low resolution of the Quest 2's display.

Usability was rated fairly highly across participants despite this, with an average SUS score of 69.90 ($SD = 14.24$) which indicates that the system's usability was slightly above average [30]. Analysing individual components of the scale, we found that several questions scored below the target values in order to ensure an average score:

- "I think that I would like to use this system frequently" ($M = 3.20$, $SD = 1.02$) Target: ≥ 3.39
- "I think that I would need the support of a technical person to be able to use this system" ($M = 3.04$, $SD = 1.11$) Target: ≤ 1.85
- "I found the system very awkward to use" ($M = 2.28$, $SD = 1.00$) Target: ≤ 2.25
- "I needed to learn a lot of things before I could get going with this system" ($M = 2.40$, $SD = 1.17$) Target: ≤ 2.09

5.1 Qualitative Results

The interviews with the students were transcribed and thematically analysed to identify trends in their responses and sentiment; we present the results of this analysis here.

5.1.1 Overall Feedback

Students overall reported that they found the system easy to use, engaging and enjoyable. Some added that they thought it would be a great tool for future-proofing geoscience skills learning as a complement to on-site learning as it can help students learn and feel more confident in their skills through practice:

> *"It was very fun, engaging, and I think this would have helped me [be] a lot more confident when out in the field" "It was a very cool experience and I learnt quite a lot in it, I think it will be a successful project for the upcoming generation in geology"*

5.1.2 Issues with the controls and rotating the compass dial

While most students found the system well structured and the lesson fairly simple to follow, some reported their perceived performance being affected due to issues with moving and manipulating the compass and a slowness in understanding the controls:

> *"Concepts were easy to follow but using the compass/controller was difficult" "Felt a bit fiddly holding the compass in the right place"*

The most common negative feedback, both in the open questionnaire responses and in the interviews, was that the students found it difficult to rotate the dial on the compass face. Rotating the dial was needed for all of the measurements in our VR experience and doing so required quite a pronounced movement of the controller around the dial similar to "stirring a pot".

> *"the part that was difficult was turning the dial on the compass you had to do some over exaggerated movements to make it turn"*

5.1.3 Following on-screen instructions

Several students also reported difficulty in following the on-screen instructions. In the interviews, students explained how they at times felt overwhelmed during the lesson with the instructions as they had to learn the compass controls, recap the theory around strike and dip, and learn how to actually perform the measurement in VR. This was found more challenging as they all had only a passing familiarity with VR and they felt that after a few times it would be easier.

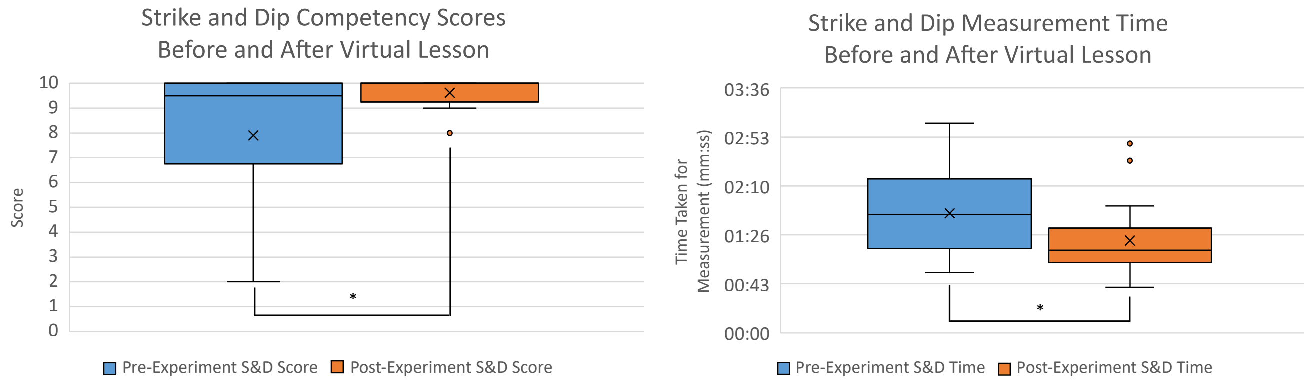

Figure 4: The pre- and post-experiment proficiency scores (left) and time taken to complete the measurement (right) for students in our first evaluation. Post-experiment scores were significantly higher than pre-experiment scores, while completion time was significantly lower, indicating students had become more proficient at measuring strike and dip as a result of completing the virtual tutorial.

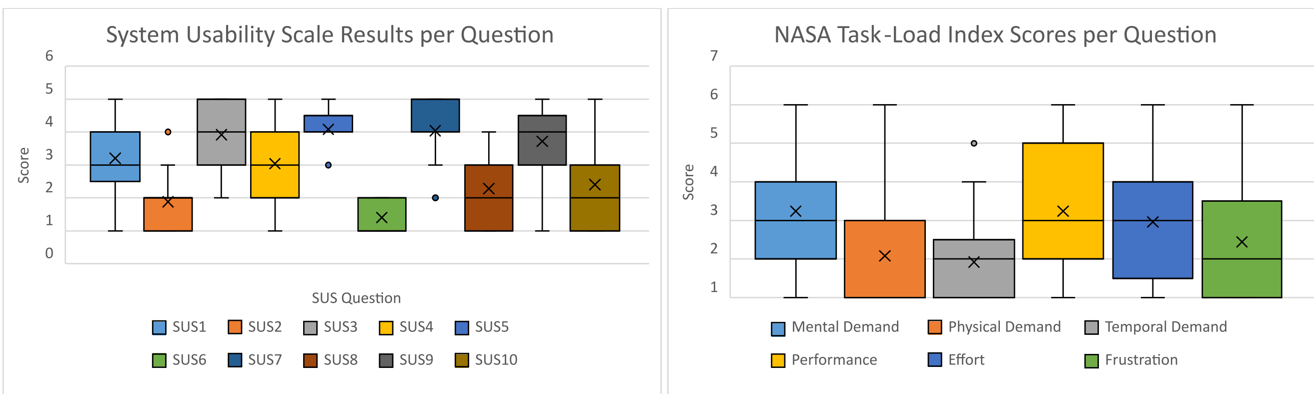

Figure 5: The SUS (left) and NASA TLX scores (right) reported by students after use of our virtual strike and dip lesson.

5.1.4 Visibility issues

Some students further mentioned visibility issues that related to the low resolution, perceived blurriness, or other visibility aspects of the display:

> *"I kind of felt like I was cross eyed the whole time"*
> *"Difficult to focus on the small writing. Had to adjust headset a lot to focus and that made the headset slightly uncomfortable."*

These visibility issues were often cited in the interviews as the reason why students had difficulty with the lesson or required more time to complete it, with students stating that the lesson was only difficult as they could not adjust the focus.

6 Evaluation Two - Novice Users

Our first study showed that the use of virtual reality for teaching practical skills could be an effective means of revision for students who had already been taught the relevant skills in the classroom, however we were also curious to see whether it could be used to teach younger students these skills.

We repeated our prior experiment on a group of first-year students from the undergraduate geoscience program. The tutorial had first been redesigned to take into consideration some of the feedback we had received:

1. The tutorial videos shown between each interactive task were re-recorded at a higher quality. Close-up shots were also superimposed on the 360° video when required, for example when the instructor was showing where on the compass to obtain a reading from.

2. A surface's strike is the direction of a horizontal line along its surface, however it's not always clear which direction this line should be traveling and so there can be two possible strike values. A new step was added to the measurement process between steps 4 and 5 of the previous procedure (as outlined in section 3) to teach students the "right hand rule" convention which removes this ambiguity; students are instructed to place their palm against the surface with their fingertips pointing down dip and then take the reading in the direction their thumb is pointing. A 3d hand model replaces their controller model for this step.

3. The pre- and post-experiment proficiency tests were administered in virtual reality rather than on a real surface. The same surface was used for both tests and was the same for all students.

These tests were also reworked to require input through a virtual numpad rather than through a multichoice selection. As most students hadn't performed a strike and dip measurement before, we also added a "don't know" option to make sure the experiment could always proceed.

Students were tested on five aspects:

1. Which of three lines displayed represents its strike?
2. What is its strike value (as a three-digit azimuth, 000-359)?
3. Which line represents its dip direction?
4. What is its dip direction (as an (inter)cardinal compass direction (eg. N, SW))?
5. What is its dip angle (as a two-digit angle, 00-90)?

The maximum score for each test was five. The study procedure was otherwise identical to the first experiment.

As with the first experiment, we had the following hypotheses:

1. (H1): Students would score significantly higher in the proficiency test after using the virtual training tool than they did beforehand.
2. (H2): Students would complete the proficiency task significantly faster after using the virtual training tool than they did beforehand.

Seven participants were recruited between the ages of 18 and 22 ($M = 19$, $SD = 1.53$) of which five were male and two were female. All but one had performed a strike and dip measurement, but only one time on a field trip several months prior to the experiment.

7 Evaluation Two - Results

All quantitative data was checked for normality using a Shapiro-Wilk test. Normally distributed non-ordinal data was compared using paired t-tests ($N = 25$, $\alpha = 0.05$).

7.1 Quantitative Results

Participants were tested on five aspects of the strike and dip measurement before and after the virtual lesson and awarded one point for each that they got correct, resulting in a maximum score of five points per test. They also had the option to select "I don't know" for each question.

The mean score for the pre-experiment test was 2.29 ($SD = 1.11$), while the mean score for the post-experiment test was 3.57 ($SD = 1.13$) (see Fig. 6. Shapiro Wilkes tests found the pre- and post-lesson scores to be normally distributed, however a t-test failed to find a significant difference between them ($t(6) = -2.00$, $p = .09$). Our first hypothesis is thus not supported.

Four of the students failed to answer at least one question in the pre-lesson test, giving up a mean of 1.14 times. In contrast, only one student failed to answer a question in the post-lesson test, and only for one question. A t-test failed to find a significant difference in the occurrence of giving up ($t(6) = 2.29$, $p = .06$).

The pre-lesson test took a mean time of 4m08s to complete ($SD = 1m23s$), while the post-lesson test took only 2m49s ($SD = 1m28s$). A t-test failed to find a significant difference in completion time ($t(6) = 1.61$, $p = .16$). Our second hypothesis is thus not supported.

Usability was rated higher in this iteration of the system, and above average in general, with a mean SUS score of 79.60 ($SD = 7.28$). Similarly, the perceived workload was rated lower with this iteration of the system with a mean score of 19.80 ($SD = 10.30$).

7.2 Qualitative Results

Overall the students found the system simple to use and the lesson easy to follow. Several students expressed that they thought virtual reality a good fit for this kind of learning, especially compared to the traditional approach where strike and dip is taught by holding a compass against a clipboard:

> *"It's easier when you can actually see a rock... because we were holding up clipboards and then putting the compass on it to do it. It was hard to visualise compared to this."*
> *"I felt like it made it more easy to grasp what actually to do. It's almost as if you were out in the field."*

However, the general consensus was that field experience is still necessary and couldn't be replaced by VR:

> *"I feel like I enjoy an in-person explanation more, but I think for actually measuring it and trying it out I think then I would use it."*
> *"I think there's a benefit to doing it, you know, actually in hand... If you can't go out into the field to do something like that then that seems like just as good a way."*

In line with the increased usability score, participants also seemed to have less trouble with the controls in this version of the system, however the low resolution of the VR display was still mentioned as a limiting factor:

> *"Yeah, it was pretty good, just sometimes the numbers were hard to read."*

The students also expressed interest in using VR to practice some of the other skills they had been learning in class, especially ones that required complex 3D visualisations.

8 Discussion

8.1 Real-World Proficiency Results

Our first hypothesis was that students would score significantly higher in the real-world strike and dip proficiency test after completing the virtual tutorial than they did beforehand. This was supported in the first experiment, with second-year students seeing an average increase of 1.72/10 in their real-world strike and dip proficiency scores, however, this was not supported in the second experiment.

Our second hypothesis was that students would complete the real-world proficiency test significantly faster after completing the virtual tutorial than they did beforehand. This was also supported in the first experiment, with students completing the exercise 28 seconds faster on average, but again was not supported in the second experiment.

The participants in our first experiment were all second-year students and so all had prior experience with measuring strike and dip in the field. Given this, it was surprising that some of them scored so low in the pre-experiment test. A possible reason for this is that between field trips, which only happen two or three times a year, students have limited opportunities to practice their field skills. This was mentioned by many of the students in the interviews, with many expressing frustration that they couldn't remember how to perform the measurement. This supports one of our key motivations in creating this system, which was to provide an effective and engaging way to practice field skills between trips, and our results speak to the effectiveness of our system as a teaching or revision tool.

The low pre-experiment scores were more excusable for the first-year students as it was their first time performing the measurement, however we were surprised to not see a significant improvement in their scores after using the system. This difference may present itself with a higher participant count, but if not then this suggests our tool is more suitable for students to revise skills they already know rather than learn new ones.

To the best of our knowledge this is the first study that explores how practical geoscience skills learned in a virtual environment can be transferred to the real world. While we focused on a single skill,

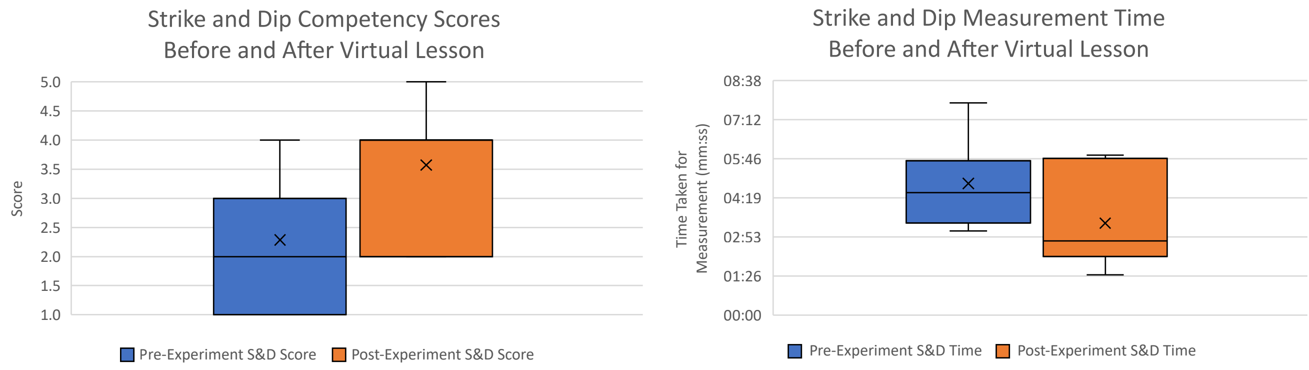

Figure 6: The pre- and post-experiment proficiency scores (left) and time taken to complete the measurement (right) for students in our second evaluation. No significant difference was found in score or completion time between the pre-experiment and post-experiment tests.

this may have implications for how we teach other geoscience concepts or even skills in similarly hands-on fields such as archaeology. Future studies should consider using real-world testing to better understand how this knowledge transfer occurs.

8.2 Simulator Sickness and Visual Discomfort

The simulator sickness symptoms reported by students tended to be fairly mild overall, which was expected as a prior history of simulator or motion sickness was one of our exclusion criteria. All but three of the students also had prior experience using virtual reality which could also explain the lack of symptoms experienced.

As seen in **??**, the only symptoms of note were “General Discomfort”, “Headache”, “Eyestrain”, and “Difficulty Focusing”, with only infrequent reports of the other symptoms. An apparent common theme between these symptoms is visual discomfort; as further explored in subsection 8.3 and subsection 8.4 this could be explained by the low resolution of the VR display, which many students cited as a reason for poor workload or usability. This suggests that the Meta Quest 2, which we chose for its affordability and portability, may not be suitable for all students and more advanced headsets may be required.

8.3 Usability

The system’s usability was rated slightly above average in both experiments, however it is clear that we have much to work on, especially when it comes to the controls. The procedure for rotating the compass’ dial was repeatedly described as awkward and cumbersome, and it became clear in the interviews that this part of the interface was poorly explained.

An animation was added to the tutorial in our second experiment that explicitly shows how this movement should be performed, however several of our participants still mentioned struggling to perform the necessary movement. Future development will investigate alternative ways to rotate the compass dial which are more user-friendly but still feel faithful to the real-world experience of using a compass.

8.4 Perceived Workload

Our results indicated that carrying out the virtual lesson incurred a low perceived workload overall, with all negative components (Mental Demand, etc.) scoring generally below the midpoint. However, in the interviews several students still reported feeling overwhelmed with the on-screen instructions.

To alleviate this, we divided the lesson into two separate parts with a break in between; the first focuses entirely on the theory, while the second focuses entirely on the practical application. This may have contributed to the lower TLX scores in the second experiment, in which none of our participants mentioned having any difficulties with the system beyond the controls.

8.5 Challenges and Limitations

A major challenge in developing this system was adapting a geological compass to the virtual environment. As discussed at length in our previous work [45], taking readings from the compass was difficult due to its small components and the VR headset’s limited resolution, but displaying the correct reading as a separate readout meant students didn’t learn how to interpret the compass themselves. We opted to (depending on the reading) either display several possible readings at once and make students pick the correct one, for example by applying the right hand rule, or to physically anchor the readout’s position to where it was obtained on the compass. This approach was not formally evaluated, but seemed to be an effective solution.

Our desire to evaluate the system with real students also proved difficult. In particular, we wanted to ensure that participation was truly voluntary without coercion, which likely meant that we only attracted already-motivated students who had less to learn from the system, and is a potential reason for our low participant count in the second experiment. In future we plan to fully incorporate the tool into the teaching schedule to ensure every student has a chance to use it outside of a testing environment.

Finally, there are fundamental differences between our two experiments that make it difficult to directly compare them. For the second experiment we were interested in testing the system as a completely self-contained module, which was partially motivated by a lack of geoscience experts to perform the testing. The pre- and post-experiment proficiency tests were thus completed within the virtual environment, whereas in the first experiment a real-world surface and compass were instead used. Several changes had also been made to the system based on feedback from the first study. While our results suggest our tool may be more effective for revision than learning, a more controlled study would be required to confirm this.

9 Conclusion and Future Work

In this paper we presented the implementation details and preliminary test results of an immersive system we developed for teaching practical geoscience skills. Through a combination of 360° video, photogrammetry, and virtual elements, students can learn how to conduct field work without regard for physical ability or environmental conditions, creating more opportunities for learning and revision.

Our initial in-class testing was successful, with students being significantly more capable of measuring strike and dip on a real-world surface after a single exposure to the virtual lesson. Feedback from students was also positive, with many enjoying the experience and seeing the system as a valuable teaching tool. Our results suggest that VR tools can be an effective alternative when real-world practice is impractical, but may not be effective when learning a new skill for the first time.

Our study results also show that the system has much room for further improvement. While reported simulator sickness and mental workload were low, students often complained about issues such as awkward controls or the Quest 2's low resolution hampering the experience and making the lesson unnecessarily difficult. The lesson was also completed alone, while in a real-world scenario students would be collaborating in groups. Future iterations of the system will investigate how these problems can be mitigated to provide a fulfilling experience while keeping hardware costs low.

We also plan to investigate other lessons that could be integrated into the learning platform. For example, many geoscience students struggle with the spatial reasoning skills required for visualising complex topographies [31], and displaying these in 3D using a VR display could help students understand these concepts [4]. We also plan to do wider consultation with teaching staff and students to discuss how best to integrate virtual technologies into the existing curriculum to ensure students are supported in their learning.

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