An Immersive Fold Instruction Module for Training Undergraduate Geologists

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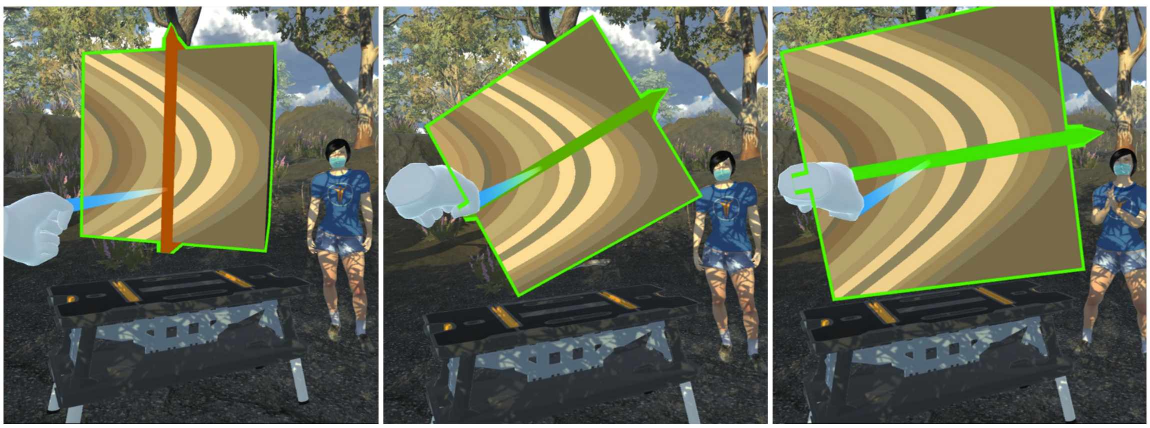

Fig. 1. A geological fold visualisation is being manipulated in the VR environment

Representation of 3D structures in rocks is inherent to the study of geology. However, these are rarely visible in nature. This poses a significant challenge for undergraduate students as it affects their understanding of how to measure, analyse, and interpret complex 3D structures. Geoscience education currently relies on the use of two-dimensional media to represent 3D structures within rock. This demonstrates a gap which could be addressed using Virtual Reality (VR). This paper presents a novel tool for the visualisation of geological folds; wave-like undulations of layered rock. With the help of a preliminary interview study, contextual inquiries, and the continued involvement of a subject-matter expert, we have begun development of an instructional module on geological folds using our novel fold visualisation tool. We conducted usability testing with naïve users, undergraduate geology students, and the subject-matter expert. Future iterations of the tool and module will involve a plethora of working examples that students can use to learn terminology, practice measurements, and develop their interpretive skills of complex 3D-geometries.

CCS Concepts: • **Human-centered computing** → **Interactive systems and tools**; Virtual reality; • **Computing methodologies** → *Computer graphics*.

Additional Key Words and Phrases: Geovisualisations, Immersive Learning

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Fig. 2. Folds photographed in Arkaroola, South Australia.

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1 INTRODUCTION

The global pandemic Covid-19 brought with it many challenges for fields of education that rely on hands-on, interactive, place-based experiences. Instructors struggled under these circumstances to provide authentic experiences to students [9]. This is especially relevant to the geosciences where students partake in field trips as a key component of their education [2, 4]. Unfortunately, even in a pre- or post-pandemic era, there are many barriers that can limit students from going into the field. These include monetary costs, site inaccessibility, weather, physically demanding labour, cultural sensitivities, time constraints, and other resource constraints (e.g., availability of instructors or equipment) [3, 5, 8, 11].

Web-based learning tools such as Virtual Field Trips (VFTs) can bring some situated context to the instruction of geoscientific concepts, so this is what many instructors turned to during the Covid-19 pandemic [1, 6]. However, situated context is not only about the visualisation of the location but also includes the context of interaction, such as tools or collaboration. During geology field trips, students use a variety of physical tools (e.g., rock hammer, hand lens, geological compass, sketch book, field maps, etc.) to apply their conceptual knowledge. Some of these tools can be taught in labs or classrooms, but others can only truly be learned when fully immersed in their context of use. This is the value of immersive technologies [13], whereby virtual learning environments (VLEs) can become situated learning environments [7]. In Virtual Reality (VR), students could be sent to a virtual geosite and interact with geological artefacts using virtual tools.

This is the motivation for the overarching project that guides the development of the novel tool described in this paper, and thus its application towards immersive education. Through a preliminary interview study, contextual inquiries, and the collaboration of a subject-matter expert, we sought to identify the gaps that a virtual, immersive instruction module could address for undergraduate geology students. We learned that geoscience education, by definition, deals in the instruction of three-dimensional concepts. However, according to our preliminary findings, we found that it can be challenging for students to visualise the relevant three-dimensional structures, and in turn, how to measure, analyse, and interpret them. This is primarily due to what we refer to as sectioning effects - 3D geometries are rarely visible in nature in their true form. Geological folds are an example of typical 3D geometries in rock that can be difficult to interpret as a result. Folds are wave-like undulations of layered rock, and for students it is often unclear where the ideal exposure plane is with reference to nature's given one (see example folds Fig. 2).

The challenge created by sectioning effects is best illustrated by observing Fig. 3. Fig. 3a shows how rock layers appear very different on the cliff versus the rock platforms. The sketch in Fig. 3b illustrates why this is the case. It shows an orange layer of "rock" embedded in non-layered "white rock". When the dipping "rock" layer is exposed in this ideal exposure plane, one can directly measure its true dip angle to be 15 degrees, as well as its true thickness. In all other possible sectioning planes, layer thickness appears exaggerated and layer dip angle is underestimated.

Fig. 3c shows complex geological folds, the deformation structure of interest to us in this paper. Fig. 3d illustrates how the folded (orange) layers, with the exactly the same geometry, appear entirely different. The vertical exposure plane reveals the true fold geometry of the upper layer, and so is the ideal plane of observation. The lower fold layer is exposed on a gently inclined surface. Consequently, the fold open angles appear smaller, the amplitudes larger, and the layer thicknesses are also exaggerated. Note that no folds are even visible in the vertical plane on the right-hand side, where it is perpendicular to the ideal exposure.

In sum, true understanding of folds and other structures in rock requires students to be trained in 3D spatial thinking. To address this problem, we have begun the development of a VR fold instruction module. The initial prototype described in this paper introduces students to declarative knowledge on what geological folds are, and how they appear in various non-ideal planes of observation. Through this exercise, the aim is to help students understand sectioning effects and why further reasoning and measurements are required to discover the true fold shape. A final prototype of the VR fold instruction module will be used in a comparative, controlled study that contributes towards the aforementioned overarching project. Ultimately, this research will contribute towards our understanding of how immersive technologies can shape future pedagogy in fields of education that rely on spatial thinking. Furthermore, it may help to improve accessibility for students who struggle with mental visualisation, or who lack opportunities to go to the field.

2 METHODOLOGY

2.1 User-Centered Approach

The overarching project that this usability study belongs to has involved several user-centered methodologies. This iteration of the fold visualisation tool forms part of an ongoing collaboration with the target stakeholders: field geology instructors and undergraduate geology students. Leading up to this first usability study, this collaboration has included an interview study, thus far conducted with seven students and ten instructors. Subsequently, two contextual inquiries have been conducted. One took place with second-year students in a week-long field-mapping exercise at a nearby beach. The other was a two-week field-mapping exercise in a remote part of South Australia. This involved third-year students who were expected to map a 12km2 zone.

Throughout the design and development of the VR fold instruction module, a subject-matter expert has been involved. Collaborative methods include unit audits to gain an understanding of the teaching style and content of lectures and workshops. In addition, regular meetings and correspondence with the subject-matter expert have ensured consistency and applicability of the instructional content.

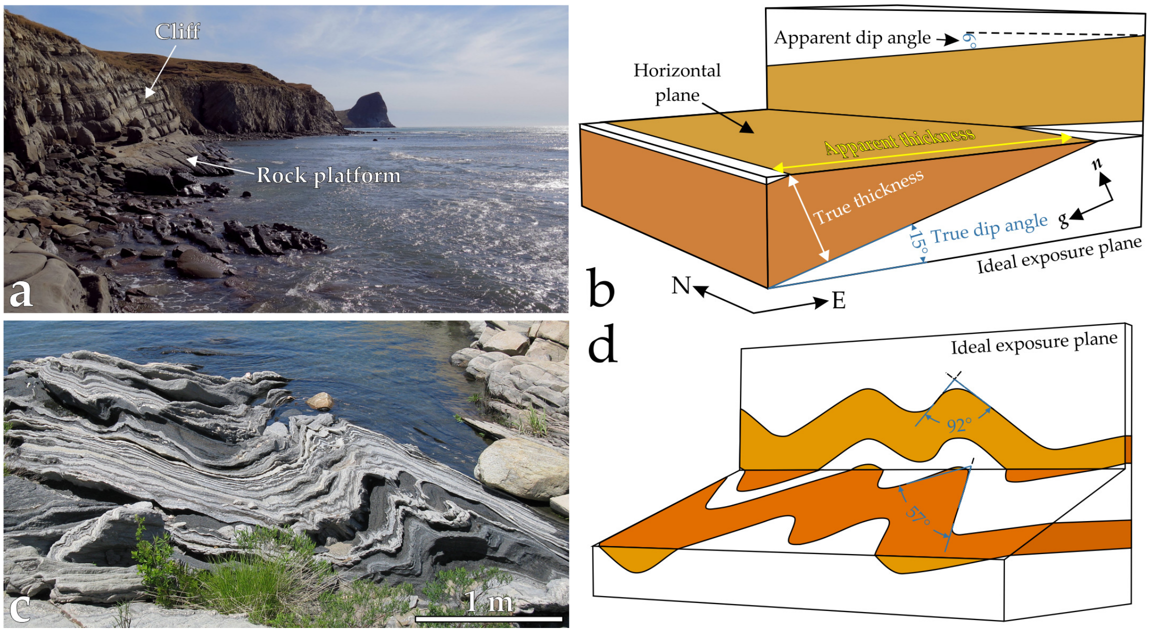

Fig. 3. a: Coastal exposures of layered sedimentary rocks, ca. 3 km SW of Castlepoint, New Zealand; b: This sketch illustrates the sectioning effects leading to the apparent-thickness and apparent-dip problem; c: Complex folds in gneisses of the Parry Sound Domain, Ontario, Canada; d: Simple 3D model of a two-layer fold train.

3 PROTOTYPE

3.1 Instruction Module Design

The instruction module is set in an environment inspired by the South Australian outback, with photographs from the second contextual inquiry as reference (see Fig. 4). This places the users in an *in-situ* environment for the purpose of the instructional activity. This initial iteration of the fold instruction module is composed of three main parts. The first is a preamble on folds, written using materials from existing structural geology lectures. Here, a virtual instructor introduces basic terminology such as antiform, synform, fold axis, and fold profile plane for naïve-user comprehension using an example fold sample. A short demonstration of the fold visualisation tool, accompanied by narration from the virtual instructor, is used to illustrate various non-ideal planes of observation.

The second part is an interactive exercise, allowing the user to manipulate a dynamic fold sample by changing the plane of observation until it matches the fold profile plane (see Fig. 1). This is performed by 'grabbing' the sample with a controller and rotating it as if the user were holding it in their hand. A large visual indicator of the axial plane is utilized here to denote the front and top of the sample, and diffuses from red to green depending on how close the user is to the solution. Haptic feedback via controller vibration provides an additional indication of solution proximity. As the user alters the plane of observation, users experience various non-ideal crosscuts that affect the visibility of the true fold shape. This should reveal why sectioning effects make folds difficult to observe appropriately in the real world. Upon correctly finding the sample profile plane, the sample becomes locked from further manipulation, but can be moved freely about the scene. The virtual instructor then directs the user to drop the sample upon a rock outcrop where the folds are then displayed (see Fig. 6). The user is tasked with repeating this process two more times, finding

Fig. 4. The immersive fold instruction environment for learning *in-situ*, inspired by the South Australian outback.

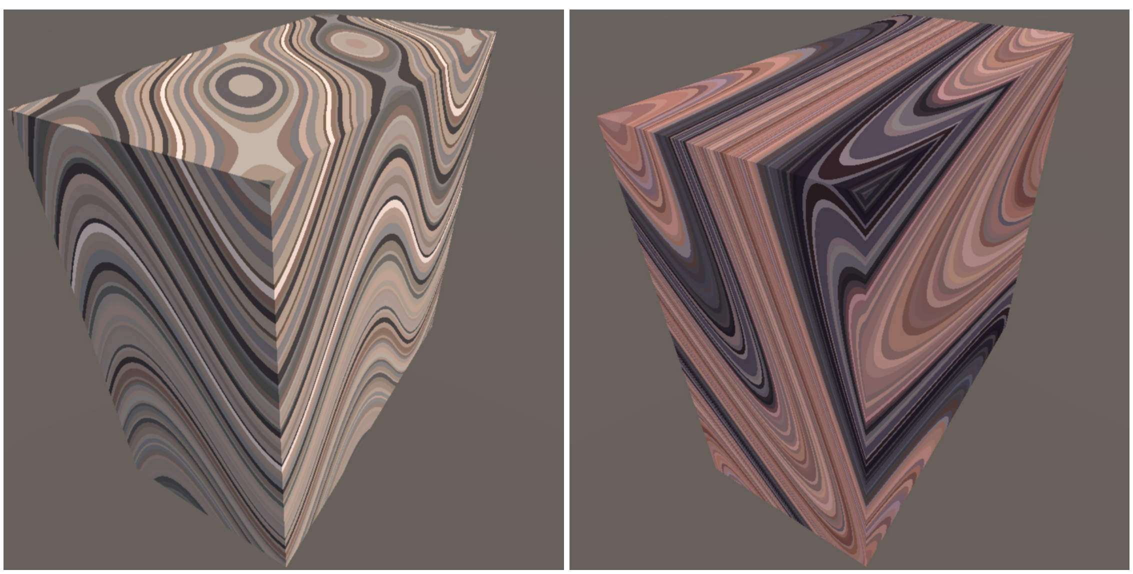

Fig. 5. Two examples of fold visualisations inspired by images of real-world folds.

the profile plane of samples with increasing complexity and fold diversity. In the final part of the module, the user is allowed to freely roam and observe multiple interesting fold samples spawned into the environment which are inspired by real-world examples (see Fig. 2 and 5).

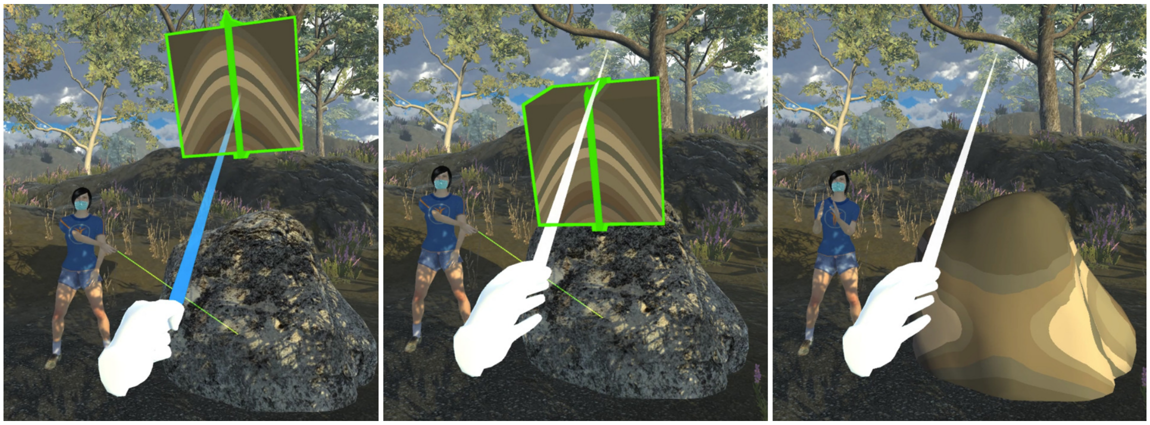

Fig. 6. The user is observed dropping the fold onto an outcrop in the environment, where the folds are then visualised.

3.2 Implementation

The prototype build was created using the latest version of Unity (2021+) in the Universal Render Pipeline (URP) for PC. The build was created using the OpenXR Toolkit and built for the Oculus Quest 2, running via Oculus Link. Standard VR interactions such as rotating, teleporting and picking up objects are all supported, alongside haptic feedback and various visual aids.

4 PILOT TESTING

4.1 Participants

Usability testing was conducted during a community event where members of the public engaged in the VR fold module, alongside several other technology demos. This same version of the initial prototype was tested with two invited participants, who completed the post-survey. The most problematic usability issues were addressed (i.e., those that inhibited progression in some cases), and the VR fold module was subsequently tested with six more naïve users, and three third-year geology students, which raises the total number of participants to eleven. Ten of the participants completed the survey, which excludes one geology student who could not finish the post-survey due to time constraints.

4.2 Procedure

The procedure began by introducing participants to the Oculus Quest 2 headset and the controllers, providing additional time for novice VR users. Once the participants were comfortable, the experimenter ran the VR fold instruction module, and participants were encouraged to think aloud. When the interactive manipulation task began, additional information was provided to users on the relevant controls, and the goal of the task. At the end of the module, participants were asked to fill in a post-survey on usability (see the instruments below) and recall. Finally, they were asked to provide any additional feedback, or to further clarify the responses they gave in the survey if they should wish to do so.

Sense of presence – iGroup Questionnaire: Participants' sense of presence was measured by using iGroup Presence Questionnaire (IPQ) [12]. The IPQ comprises 14 items on a 7-point Likert scale ("strongly agree" to "strongly disagree"), which add up to three scales: (a) "spatial presence" assesses the physical sense of actually being in the virtual environment (e.g., "I felt present in the virtual space"); (b) "involvement" evaluates the amount of attention focused on the virtual stimuli (e.g., "I was completely captivated by the virtual world"); and (c) "realism" reflects the participant's perception of the virtual environment as real and believable (e.g., "The virtual world seemed more realistic than the real world").

Enjoyment: Participants' enjoyment was measured using the Intrinsic Motivation Inventory (IMI; [10]). This scale has seven, 7-point Likert scale items (1 - Not at all; 7 - Extremely) that ask the users to indicate how much they agree with a statement (e.g., "I enjoyed doing this activity very much.", "This activity was fun to do.").

Participants were asked four multiple-choice questions to measure whether they could identify folds, an antiform, a synform, and the definition of the profile plane. For the first three, they were given images for identification, and were asked to choose all apply to the question, with each having two correct answers out of four options.

4.3 Results

Participants experienced a moderate sense of presence (M=4.45, SD=.95) and involvement with the activity (M=4.60, SD=.80), and reported low consistency with the real world (M=3.75, SD=.54). The latter is expected as the novel interactions within the VR module is not possible to achieve in the real world. Participants reported high enjoyment of the interactions (M=5.54, SD=1.61).

4.3.1 Recall. Eight participants identified two correct folds. One identified only one of them where the other selected an inaccurate image as a fold. For both antiform and synform questions, again, eight people identified both correctly, two people identifid them inaccurately for both questions. For the final question, nine participants chose the correct definition of the fold profile. Six participants answered all questions correctly. Overall, a majority of the participants answered the questions correctly.

4.3.2 Qualitative Responses. Usability testing with the three geology students produced overall positive responses. Following the instruction module task, they were asked orally about their thoughts on the pedagogy of the fold visualisation tool. One participant expressed that they found the virtual instructor to be helpful in guiding the user through the terminology with the example fold sample. They added that they would like to see more terminology introduced in this manner, including examples of *hinges* and *limbs*. Two participants expressed that they would have liked to see the instructor do the manipulation task herself, to demonstrate the intended visual outcome of the exercise. While the geology students indicated that they understood the terminology, they felt confused about whether the large indicator referred to the fold axial plane, or the fold profile plane. All three participants verbally indicated that they enjoyed the visual and auditory environment. One of the participants had been present at the contextual inquiry that inspired the environment. They expressed "Wow, you got the crows too!" during the task, referring to the audio in the environment and its similarity the real-world field trip. Finally, all three participants indicated that they would have liked to experience this module earlier on in their studies when first introduced to sectioning effects of folds (typically in second-year for these students).

Usability testing was also conducted separately with the subject-matter expert. Their feedback was positive overall but revealed some points of improvement. Like the students, they commented on the ambiguity of the large indicator as the fold axial plane or the fold profile plane. The instruction to them felt slow with long pauses after the virtual instructor had finished speaking, indicating the importance to keep users mentally engaged and active. A suggestion was made to create a version of the VR fold instruction module that users could engage in without the preambles and tutorial-like explanations. The purpose of which would allow repeated use of the module in the students' own time. During the manipulation task, the subject-matter expert expressed the importance of being able to observe multiple sides of the sample at once. They spent some time moving around the sample before even starting to interact. This was difficult due to the limitations placed on where the user could move to in the environment. The same comment was applied to when the folds were placed onto the boulder in the environment (Fig. 6). The ability to walk around it easily was something the expert felt was missing. Additionally, they contributed that the folds visualised on the outcrop is a good way to demonstrate sectioning effects. Fold-like shapes can appear in planes of observation that are nowhere near the true fold shape in this example. For future iterations, they suggested adding the ability to slice the folded outcrop where students believe the fold profile plane to be. In addition, the folded outcrop could serve as a standalone instruction tool to demonstrate sectioning effects in a curated VR teaching experience. All these suggestions considered, the subject-matter expert indicated that they would use the module, as is, in their workshops already.

4.4 Discussion

4.4.1 Instruction Fold Module. From the time with the geology students and subject-matter expert, several ideas were discussed on how to expand upon the instruction module. This initial prototype exists as a guided tool for introducing geology students to folds and related sectioning effects. However, sectioning effects could be introduced for more basic geometric structures to begin with (e.g., ellipsoids as found as clasts in a conglomerate). In addition, another novel tool could be used to split open the outcrop or fold samples by users. This is yet another interaction that would show students the complexity introduced by sectioning effects. More in-depth terminology can be introduced into the module to make it a fully self-functioning activity. The virtual instructor should be made capable of explaining all necessary instruction to this end. Interesting opportunities arise when considering the fold visualisation tool as something that instructors can input parameters for on the fly, perhaps in a workshop environment. Alternatively, randomised fold samples would allow students to test themselves independently and repeatedly. Another significant way to expand the module would be to include more interactivity for students in the form of measurement-taking. This would more closely approximate the experience of the VR module to real-world workshops, and prompt students more actively to use spatial thinking.

4.4.2 Future Research. The future of the fold instruction module will see expanded content, additional interaction tools (both novel and existing), and more broad use cases within geoscience education. Iterative design of the module will continue through the collaborations described and usability testing. For now, little is to be said on the impact on learning and developed spatial thinking abilities. In the future, a final prototype will be used in a comparative, controlled study with undergraduate geoscience students prior to the application of their skills in a field-mapping exercise. The research resulting from this work will contribute towards the broader field of immersive learning by measuring a wider array of student learning outcomes. It will also ideally be applied to existing student assessments to truly understand the effects of the VR module compared to traditional pedagogy.

5 CONCLUSION

The usability testing of the VR fold instruction module has revealed several paths towards improvements. Regardless, users appear to engage with the content in a positive manner, and the subject-matter expert has a positive outlook on the applicability of the instruction module towards their existing classwork. This provides some indication of the success of the module, and therefore reason to pursue further iteration and development of novel interaction tools.

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Australian Research Council

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