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GC Insights: Designing for full-phase inquiry in virtual fieldwork - upper secondary school students' exploration of extinction events

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Abstract. When designing virtual field courses it is challenging to create a truly explorative course element. In relation to theories of student learning, this has been problematised, and more inquiry and student-centred virtual fieldwork has been proposed to allow for authentic exploration and engagement. Here, we outline the development of a full-phase inquiry virtual fieldwork activity using 360 videos with additional classroom tools that allows students to collect data, work out hypotheses independently, and combine with known science relationships to draw geologically viable conclusions.

1 Introduction

Technological advancement has made it possible to produce low-cost, user-driven virtual field experiences with a variety of aims (Foley et al., 2024; Rojas-Sánchez et al., 2023), including in the geosciences (Cliffe, 2017; Dolphin et al., 2019; Klippel et al., 2020). Movements towards using virtual fieldwork in learning situations were favoured during the COVID-19 pandemic when teaching in the field became impossible in many locations (e.g. Whitmeyer and Dordevic, 2021; Bond and Cawood, 2020; Jeffery et al., 2020). In addition, a growing recognition of the inequities associated with physical fieldwork has led to an increased interest in developing virtual field trips (Malm et al., 2020; Posselt and Nuñez, 2022; Guillaume et al., 2023; Hurrell et al., 2025). Despite these developments, the research field especially at the upper secondary level is still grappling with how to combine virtual fieldwork and the learning approach of inquiry, although inquiry as a pedagogical approach has long been a focus in relation to learning science (Anderson, 2002). Here, we explore how virtual fieldwork and inquiry can be combined, outline the grounding pedagogical intentions, and make the inquiry lesson available in the supplementary material, so that geoscience teachers can adjust and add content to fit their student population and local curriculum.

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2 Background: virtual fieldwork and inquiry

Teaching in the field is a central pedagogical practice in Earth science, where materials and processes are connected, theoretical knowledge is made relevant, and through this, enhance students' understanding of key scientific principles (Elkins and Elkins, 2007; Stokes and Boyle, 2009; Mogk and Goodwin, 2012). While the close connection between exploratory fieldwork and scientific advancements is well established, the link between *exploration* and *teaching in the field* is less prominent. The open exploration of scientific fieldwork is substituted with designed field trips or excursions with selected locations or outcrops. According to Granshaw and Duggan-Haas (2012), this linear design lacks the fundamental explorative nature of being in the field, and they make a distinction between a field *trip* designed with a pre-determined, linear structure in contrast to a field*work* design that includes exploration. In a linear design, the active movement through different geologic times, can develop appreciation for situated fieldwork settings (Jolley et al., 2018) but often the pre-designed does not allow for authentic student inquiry. To create opportunities for open exploration is also a challenge in a virtual fieldwork design, where the developer will have pre-selected content (Hurst, 1998). Here, we attempt to create a virtual field environment where the student's task is to explore and collect data as they enter the virtual world, and we apply an inquiry design to achieve this.

Technological innovations have created a new generation of Earth science courses (e.g. Senger et al., 2021; Whitmeyer and Dordevic, 2021; Cawood and Bond, 2019; Bond and Cawood, 2020; Herodotou et al., 2020; Bond et al., 2022; Engel et al., 2023). However, while geoscience instructors, computer scientists, psychologists, etc., have embraced the opportunity to develop new formats and measure the impacts of these technologies, Glenn Dolphin and colleagues (2019) find that while they tried to mitigate a large student population problem with virtual reality, they found a fundamental pedagogical problem of how we teach geology. They propose to teach "geology with more emphasis on how geology works" (Dolphin et al., 2019, p. 114) in relation to understanding of the relationship between inference and observation in fieldwork. This emphasis is central to inquiry-based learning; here, teaching is structured around students' explorations, and the design precisely distinguishes between inference and observation. The ideas behind can be traced back to the early twentieth century, when John Dewey described five phases of reflective thinking (Dewey, 1933) which, for example, inspired problem-based learning and concepts of learning cycle models (Heiss et al., 1950; Karplus and Thier, 1967). These models are based on learners exploring for themselves as they create valid arguments based on observations or data. In the 1980s, these concepts were formalised in science education as the '5E model' introducing the phases Engage, Explore, Explain, Expand, and Evaluate emphasising the sequencing of the phases supporting student learning (Bybee, 2009; Bybee et al., 2006). Decades later, both Minner et al. (2010) and Anderson (2002) summarise the development until the start of the millennium. Although research on inquiry does not produce definitive results due to the complex character of the phenomena, much has been done to include inquiry in curriculums and training science teachers in inquiry practices and there is a general acceptance within

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science education that inquiry fosters learning and engagement in science (Furtak et al., 2012; Rönnebeck et al., 2016; Madsen et al., 2020).

3 Results

The multi-phase inquiry design with the constraint of making student explorations possible is presented in Figure 1. Detailed explanations, additional figures, and materials are provided in the supplementary materials, link provided below.

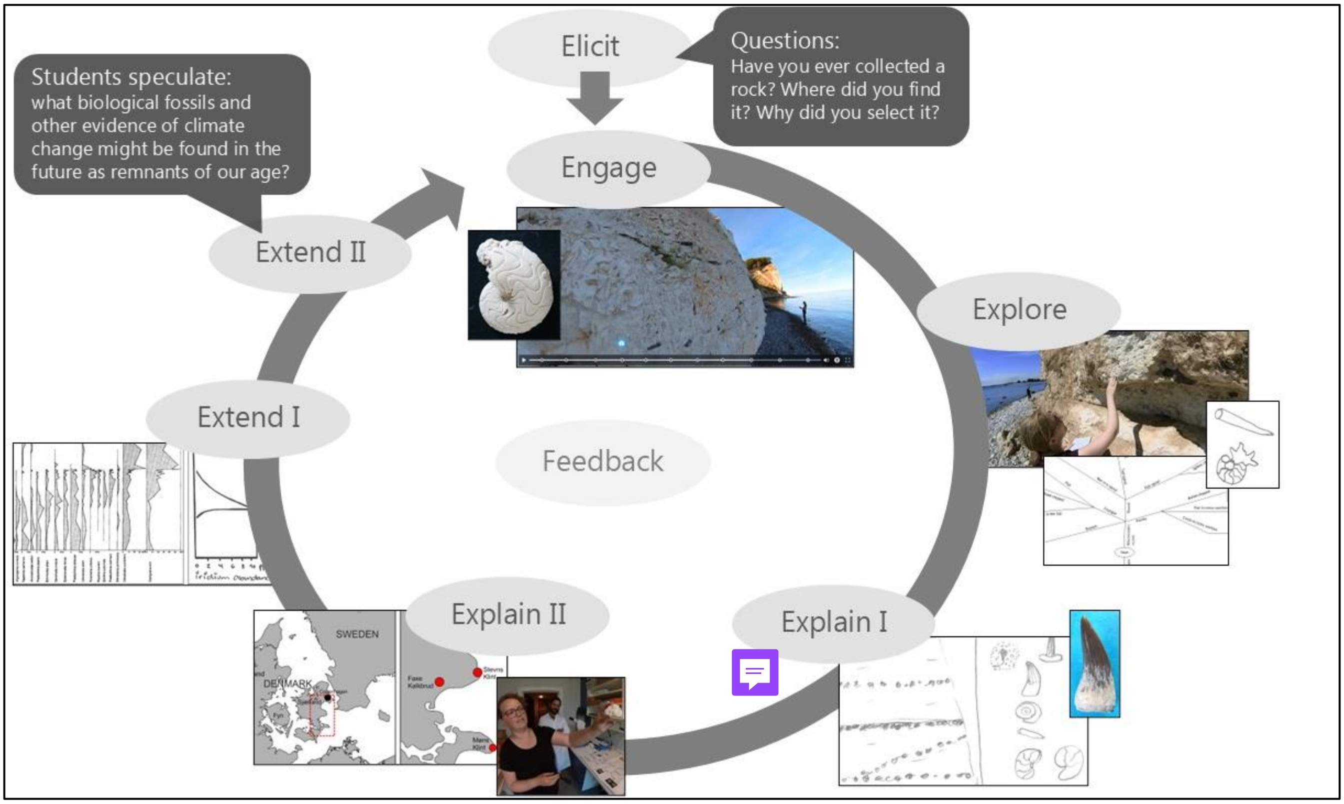

Figure 1: Overview of the inquiry phases of the lesson designed as a multi-phase inquiry model with *Elicit*: Students prior knowledge, *Engage*: Creating interest in working out the geological story, *Explore*: Students independent exploration, *Explain I*: Students interpretation, *Explain II*: Teacher validation and expansion, *Extend I*: Teacher introduces data-sheets, *Extend II*: Students design future geological deposits, and *Feedback*: Continuous formative feedback for students and teachers during the activity. The cyclic design emulates science using one exploration's outcomes to engage students in another inquiry cycle. The design is meant to communicate that finding 'an answer' is not an end to a science investigation but a possible motivation to continue exploration. Feedback is placed in the middle indicating that the students as well as the teacher get and provide feedback throughout the inquiry.

4 Discussion: to what extent is inquiry learning compatible with fieldwork via virtual reality?

Inquiry, regarded by many as a goal in science education, whether it is in person, in the field, in the laboratory, or online requires a range of skills, attitudes and content knowledge that all need embedding around the learning activity. Previously,

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virtual field trips have been used in both tertiary and secondary education to replace, or augment real field trips, and to teach specific skills related to fieldwork. Most contain multiple elements from inquiry exercises (Bonali et al., 2021; Bond and Cawood, 2020; Dolphin et al., 2019; Madsen et al., 2021; Guillaume et al., 2023; Evelpidou et al., 2022, Pugsley et al., 2022; Senger et al., 2021; Saha et al., 2023). *Elicit* was added to the basic inquiry phases by Eisenkraft (2003) and used in Watson et al. (2022) with discussion boards to engage with prior learning prior to the interactive 3D activities. The *Explore* stage of the inquiry process has attracted teachers and researchers since within these environments students can safely and easily move over large virtual distances and across scales (e.g. Houghton et al., 2015). An element that we added to our 360 videos was the use of microfossils hidden within the 360 video. However, the inherent dilemma of virtual fieldwork is the lack of a physical component and therefore the explore component is never a true representation of exploring in real life. Our intention has been to create flexibility, where even the *Explore* component of the inquiry exercise within the virtual experiences can be augmented, by teachers adding rock samples or physical fossils, if they have a collection.

In our inquiry lesson, the *Explain* I and II components are critical to scaffold knowledge and approaching questions like: *How does the fossil record translate into time and geological history* and *How do we compare and contrast different physical sites*. During fieldwork and during this exercise this scaffolding process is expected to occur as students ask questions of each other and their teachers Peer learning being an important component of fieldwork in nature (El-Mowafy, 2014; Nyarko and Petcovic, 2023).

The *Extend* I and II activities are used to approach higher levels in Bloom taxonomy where knowledge can be interpreted (Anderson and Krathwohl, 2001). Teacher prompts are relied upon here, as they are commonly done in the field, and this has been implemented in other virtual environments (e.g. Engel et al., 2023). We suggest these extension activities can be explicitly embedded in a laboratory/workshop classroom environment after the virtual tasks are completed, as a part of classroom discussion. Additionally, we suggest linking past climate change and extinction events to inform our current knowledge with the aim of using an engaging fossil hunting experience to motivate students to think about authentic problems, such as the sixth mass extinction event (Kolbert, 2014).

The inquiry approach offers the opportunity to scaffold the necessary knowledge, skills and attitudes around a field experience where many of these skills and knowledge may not be directly related to the fieldwork but are critical to true inquiry (Houghton et al., 2015, Kennedy et al., 2024). The ambition to build a full-phase inquiry lesson with a virtual reality component has challenged the format without making it a ‘show and tell’. In this inquiry lesson there is a good chance that the motivation from the rich digital 360 environment and the goal of mapping a genuine geological problem will carry students beyond just wanting a ‘correct’ answer. The acknowledgement and use of student answers upon which the teacher builds what scientists think (see Figure 1) offers students the rewards of figuring out a reasonable explanation of a scientific problem and having their thinking recognized.

Supplement

The full-phase inquiry lesson related to this article is available online at:

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Author contributions

RHM, KRSH, RE, LMM, BK, JM and NRT co-designed the material, RHM, RE, LMM, BK conceived the study and wrote the original draft; KRSH and LMM tested the lesson; JM and NRT reviewed and edited the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

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