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GC Insights: Designing for inquiry in virtual fieldwork

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Abstract. In virtual field courses, it is challenging to design a truly explorative course element. In relation to theories of student learning, more inquiry and student-centred virtual fieldwork have been proposed to facilitate student exploration and engagement. Here, we outline the development of an inquiry virtual fieldwork activity using 360° videos, along with additional classroom tools that allow students to collect data, develop hypotheses independently, and combine them with known science to draw geologically viable conclusions.

1 Introduction

Technological advancement has enabled the production of low-cost virtual field experiences with a variety of aims (Cliffe, 2017; Dolphin et al., 2019; Klippel et al., 2020; Foley et al., 2024; Rojas-Sánchez et al., 2023). The use of virtual fieldwork in learning situations was favoured during the COVID-19 pandemic, when field-based teaching became impossible in many locations (e.g., Whitmeyer and Dordevic, 2021; Bond and Cawood, 2021; Jeffery et al., 2021). 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 integrating virtual fieldwork with the inquiry-based learning approach. However, inquiry as a pedagogical method has long been a focus in science teaching and learning (Anderson, 2002). Here, we present a virtual fieldwork inquiry lesson, specify the pedagogical intentions behind the design, and make the lesson available in Malm (2026).

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, students' understanding of key scientific principles is enhanced (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 replaced by designed field trips or excursions to selected locations or outcrops. According to Granshaw and Duggan-Haas (2012), this linear design lacks the fundamental exploratory nature of fieldwork, and they make a distinction between a field *trip* designed with a predetermined, linear structure and a field*work* design that includes exploration. In a linear design, active movement through different geologic times can foster appreciation for situated fieldwork settings (Jolley et al., 2018), but the pre-design often does not allow for student inquiry. Creating opportunities for exploration is also a challenge in a virtual fieldwork design, where the developer pre-selects content (Hurst, 1998). Here, we create a virtual field environment in which the student's task is to explore and collect data as they enter the virtual world and to produce their own hypotheses. We use an inquiry-based learning 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, 2021; Herodotou et al., 2020; Bond et al., 2022; Engel et al., 2023). However, as geoscience instructors, computer scientists, and psychologists 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 teaching "geology with more emphasis on how geology works" (Dolphin et al., 2019, p. 114) to better understand 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 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 Their, 1967; Kolb, 1984). 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, and emphasising the sequencing of these phases to support 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 learning science, much has been done to include inquiry in curriculums and training science teachers in inquiry practices. There is now a general acceptance within 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 inquiry lesson is designed for Danish upper secondary students (ages 16–19) enrolled in an elective Physical Geography course. The module can be run as a single 1.5 h module or as two 1.5 h modules, depending on prior experience with inquiry and/or virtual environments. The learning goals for the lesson: students should be able to observe and distinguish three field localities, classify their rocks and fossils, determine their relative ages, and use this information to infer past environments and geological time. The localities are Møns Klint, Stevns Klint, and Faxe Kalkbrud, which represent three connected but distinct geological periods around the end of the Cretaceous, at the Cretaceous-Paleogene boundary, when life on Earth underwent a severe mass extinction 66 million years ago. The lesson ends with students using their knowledge of past mass extinctions, geological deposits, and environmental change to predict future geological deposits from our time, thus linking past and future climate change. The inquiry lesson is presented in Fig. 1. Detailed explanations, additional figures, and materials are provided in Malm (2026).

4 Discussion: To what extent does virtual reality fieldwork comply with the principles of inquiry learning?

Inquiry, regarded by many as a goal in science education, whether in person, in the field, in the laboratory, or online, requires a range of skills, attitudes, and content knowledge that all need to be embedded around the learning activity. Previously, virtual field trips have been used in both tertiary and secondary education to replace or augment real field trips and to teach specific fieldwork skills and most contain multiple elements from inquiry exercises (Bonali et al., 2021; Bond and Cawood, 2021; 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 aims to engage or map prior knowledge. An example is Watson et al.'s (2022) use of discussion boards before the interactive 3D activities, and we used open-ended questions. The *Explore* stage of the inquiry process has attracted teachers and researchers, as within these environments, students can safely and easily move over large virtual distances and across scales (e.g., Houghton et al., 2015). An element we added to our 360° videos was the use of both micro- and macrofossils, which enables exploration on multiple scales simultaneously. This challenged the students; nonetheless, in this case, both scales are needed because the fossils establish a link between two distinguishable environments, which is one of the indicators of environmental change that the students need to work out to solve the problem.

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

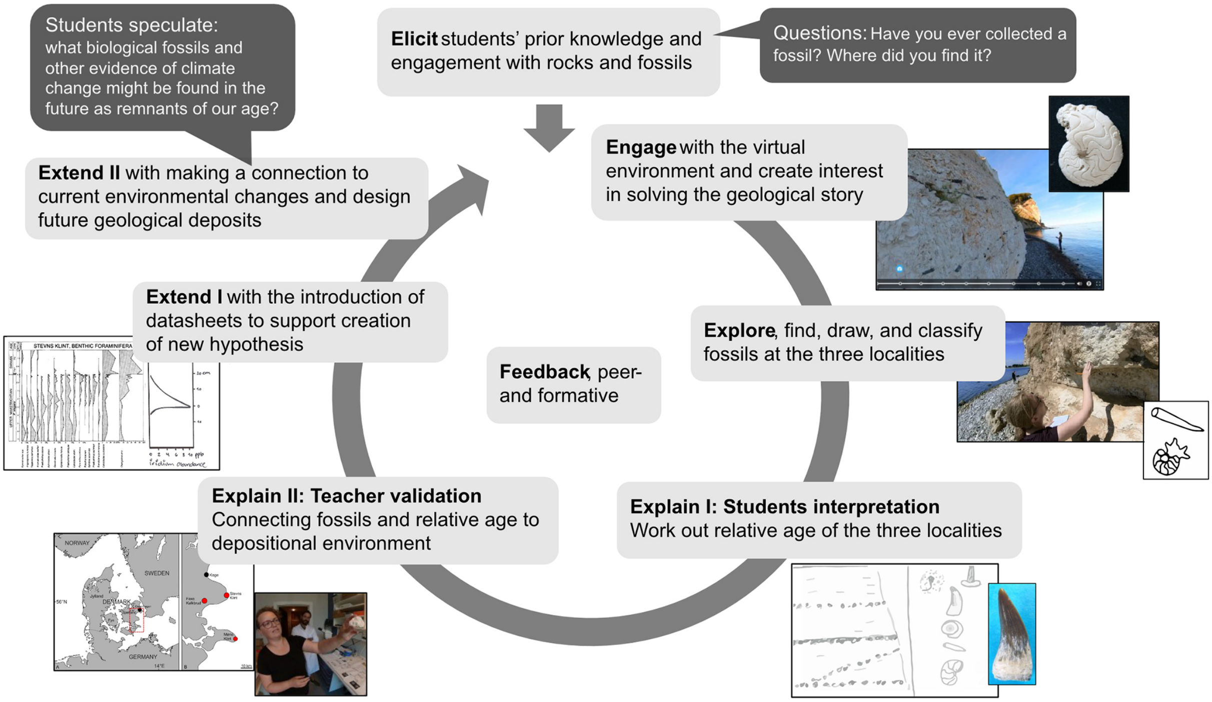

Figure 1. Overview of the inquiry phases of the lesson designed with Elicit: Students prior knowledge, *Engage*: Creating interest in working out the geological story, *Explore*: Students independent exploration, *Explain I*: Students interpretation, *Explain II*: Teacher validation and expansion, *Extend I*: Teacher introduces datasheets, *Extend II*: Students design future geological deposits, and *Feedback*: Continuous formative feedback for students and teachers during the activity. The cyclic design emulates science by using one exploration's outcomes to engage students in another inquiry cycle. The design is meant to communicate that finding "an answer" is not the end of a scientific investigation but a possible motivation to continue exploration. Feedback is placed in the middle, indicating that students and the teacher both give and receive feedback throughout the inquiry. The screen captures show the virtual environment created by 360° video recordings modified with the software *Thinglink*.

edge from the three localities to the shared story in the classroom.

The *Extend* I and II activities are used to approach higher levels of the Bloom taxonomy, where knowledge can be interpreted (Anderson and Krathwohl, 2001). Teacher prompts are relied upon here, as they are commonly used in the field and have been implemented in other virtual environments (e.g., Engel et al., 2023). 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 understanding and to use an engaging fossil-hunting experience to motivate students to consider 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., 2025).

5 Conclusion

The ambition to build an inquiry lesson with a virtual reality component has challenged the format without making it a "show and tell". In this inquiry lesson, 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 students' answers on which the teacher builds what scientists think offer students the reward of figuring out a reasonable explanation of a scientific problem and having their thinking recognised.

Data availability. The inquiry lesson is available at: https://doi.org/10.5281/zenodo.18596104 (Malm, 2026)

Author contributions. RHM, KRSH, RE, LMM, BK, JM and NRT co-designed the material; RHM, RE, LMM, and BK conceived the study and wrote the original draft; KRSH and LMM tested the lesson; JM and NRT provided the geological and palaeontological background for the project, reviewed, and edited the manuscript.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Ethical statement. Ethical approval was not required for this study as it is conceptual work that did not involve the collection of empirical material.

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