

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-degree 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, 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 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 the supplementary material.

2 Background: virtual fieldwork and inquiry

30 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 often replaced by designed field trips or excursions to selected locations or outcrops.

35 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 *fieldwork* 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 students' exploration is also a challenge in a virtual fieldwork design, where the developer pre-selects content and activities

40 (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, 2020; Herodotou et al., 2020; Bond et al., 2022; Engel et al.,

45 2023). However, while 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

50 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 Thier, 1967; Kolb, 1984). These models are in various ways focused on linking learner's explorations and experiences as they create valid arguments based on observations or data to reflective thinking. In other

55 words, they focus on combining hands-on with minds-on activities. 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

60 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 enrolled in an elective Physical Geography course. The module can be run as a single 1.5-hour module or as two 1.5-hour 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 Figure 1. Detailed explanations, additional figures, and materials are provided in the supplementary materials.

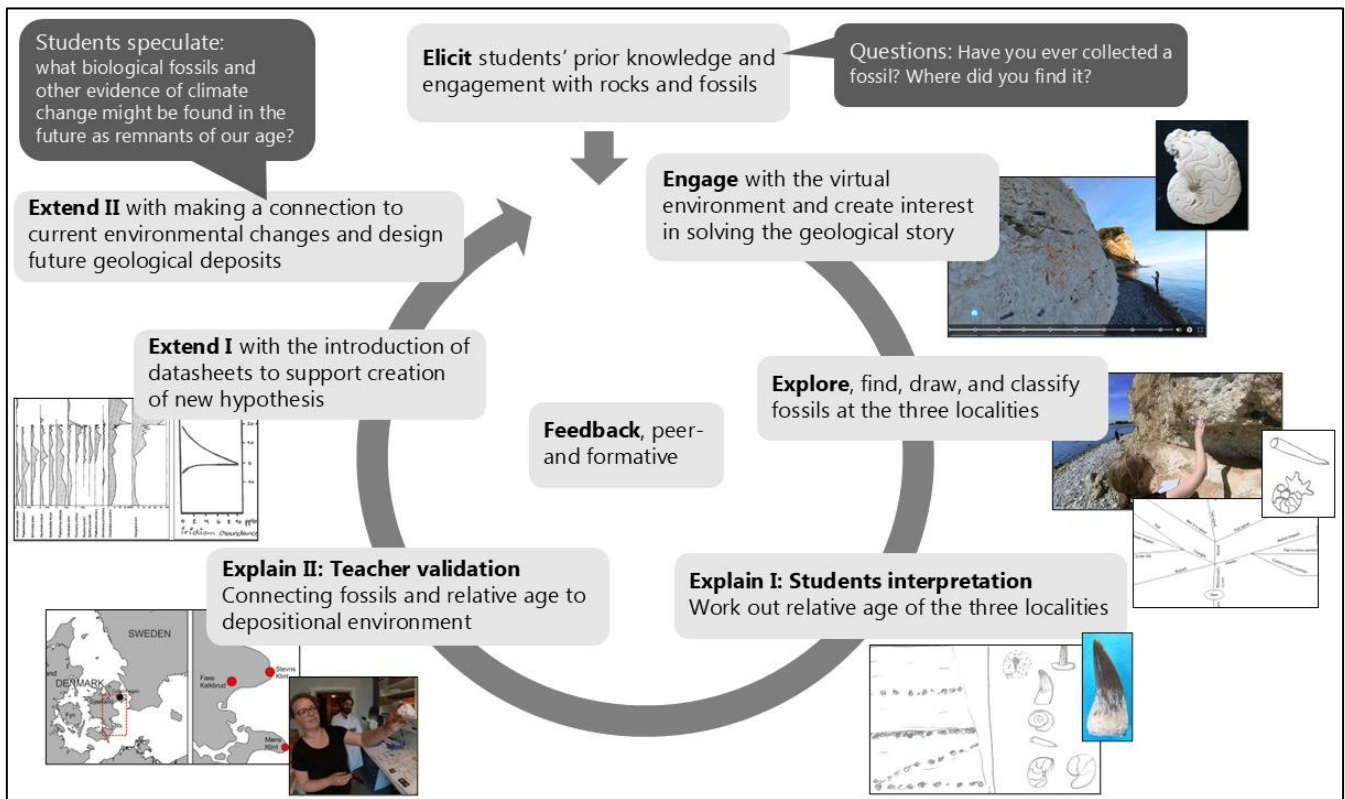


Figure 1: Overview of the inquiry phases of the lesson designed with *Elicit*: Students prior knowledge, *Engage*: Creating interest in working out the geological story, *Explore*: Students independent exploration, *Explain I*: Students interpretation, *Explain II*: Teacher validation and expansion, *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-degree video recordings modified with the software *Thinglink*.

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

The developed inquiry lesson offers the opportunity to scaffold knowledge, skills and attitudes around a virtual field experience where students are engaged in combining open-ended explorations with reflective thinking. The ambition to build an inquiry lesson with a virtual reality component has challenged the format without making it a 'show and tell'. In the 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 (see Figure 1) offer students the reward of figuring out a reasonable explanation of a scientific problem and having their thinking recognised.

To obtain this, *Elicit* was added to the basic inquiry phases as suggested by Eisenkraft (2003) aiming to engage and map students' prior knowledge. This can be done in various ways, for example by using discussion boards (Watson et al., 2022) initiating open-ended questions and dialog before the interactive 3D activities. The *Explore* stage of the inquiry process has attracted teachers and researchers, as within these virtual 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-degree videos was the use of both micro- and macrofossils, which enables exploration on multiple scales simultaneously. This challenges students, however, 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 knowledge 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 as a part of classroom discussion in a laboratory/workshop classroom environment after the virtual tasks are completed. 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 a sixth mass extinction event (Kolbert, 2014).

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. Most contain multiple inquiry exercises (Bonali et al., 2021; Bond and Cawood, 2020; Dolphin et al., 2019;

115 Madsen et al., 2021; Guillaume et al., 2023; Evelpidou et al., 2022, Pugsley et al., 2022; Senger et al., 2021; Saha et al., 2023; Kennedy et al., 2025). We add to this field, by sharing the development of an inquiry virtual fieldwork activity using 360-degree 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.

120 **Supplement**

The inquiry lesson is available in the supplementary material.

Author contributions

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

Competing interests

The authors declare that they have no conflict of interest.

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