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 In virtual field courses, it is challenging to createdesign a truly explorative course element. In relation to theories of student learning, this has been problematised, and more inquiry and student-centred virtual fieldwork hashave been proposed to allow for authenticfacilitate student exploration and engagement. Here, we outline the development of a full-phasean inquiry virtual fieldwork activity using 360-degree videos, along with additional classroom tools that allowsallow students to collect data, work outdevelop hypotheses independently, and combine them with known science relationships to draw geologically viable conclusions.

1 Introduction

Technological advancement has made it possible to produce enabled the production of 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; Foley et al., 2024; Rojas-Sánchez et al., 2023). Movements towards using). The use of virtual fieldwork in learning situations werewas favoured during the COVID-19 pandemic, when field-based 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 combineintegrating virtual fieldwork andwith the inquiry-based learning approach of inquiry, although. However, inquiry as a pedagogical approachmethod has long been a focus in relation to science teaching and learning science (Anderson, 2002). Here, we explore howpresent a virtual fieldwork and inquiry can be combined, outlinelesson, specify the grounding pedagogical intentions behind the design, 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~~.

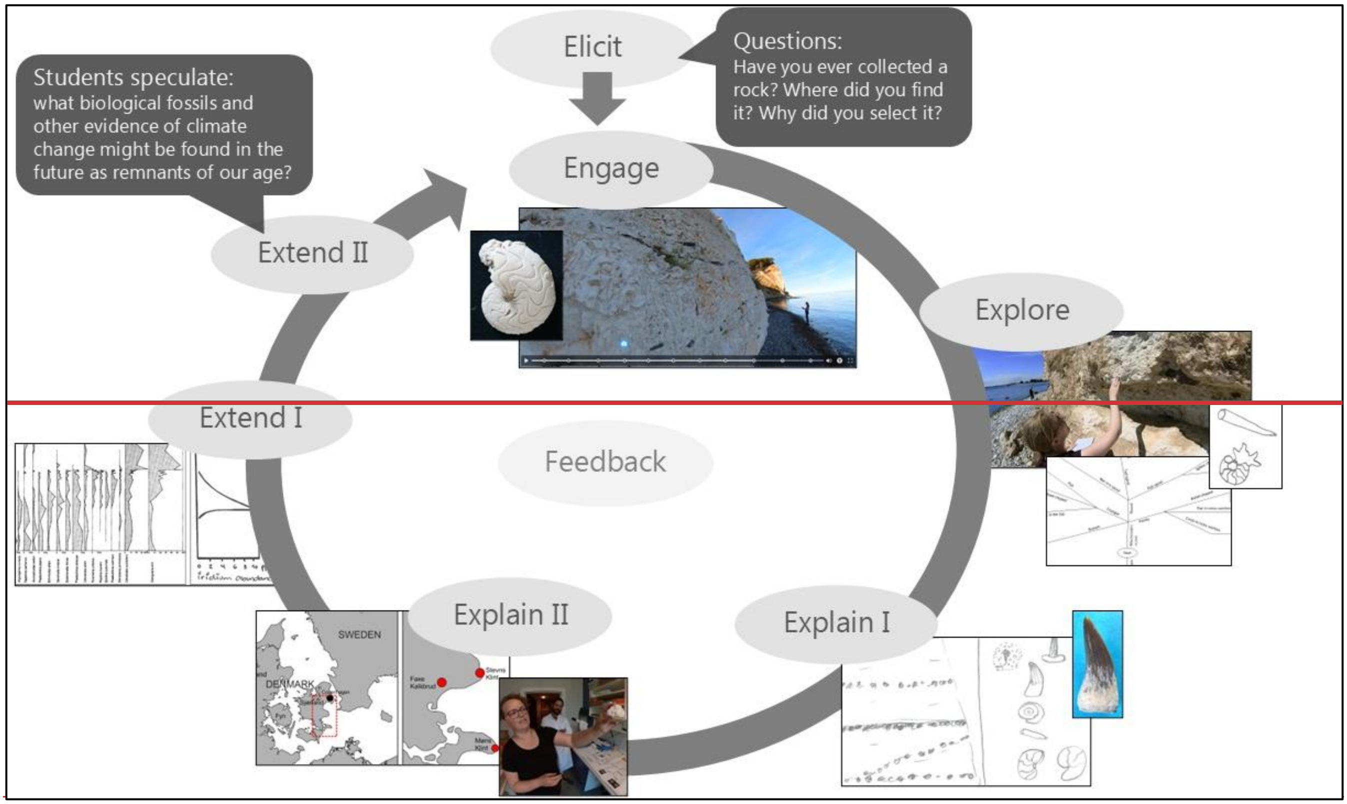
2 Background: virtual fieldwork and inquiry

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'~~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 ~~substituted with~~often replaced by designed field trips or excursions ~~with~~to selected locations or outcrops. According to Granshaw and Duggan-Haas (2012), this linear design lacks the fundamental ~~explorative~~exploratory nature of ~~being in the field~~fieldwork, and they make a distinction between a field *trip* designed with a ~~pre-determined~~predetermined, linear structure ~~in contrast to~~and a field*work* design that includes exploration. In a linear design, ~~the~~ active movement through different geologic times~~,~~ can ~~develop~~foster appreciation for situated fieldwork settings (Jolley et al., 2018~~)~~), but the pre-design often ~~the pre-designed~~ does not allow for ~~authentic~~ student inquiry. ~~To create~~Creating opportunities for ~~open~~students' exploration is also a challenge in a virtual fieldwork design, where the developer ~~will have~~ pre-~~selected~~selects content and activities (Hurst, 1998). Here, we ~~attempt to~~ create a virtual field environment ~~where~~in which the ~~student's~~student's task is to explore and collect data as they enter the virtual world~~, and we apply~~ 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., 2023). However, while geoscience instructors, computer scientists, and 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 "~~teaching "geology with more emphasis on how geology works~~"~~" (Dolphin et al., 2019, p. 114) ~~in relation to understanding of~~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 ~~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; Kolb, 1984). These models are ~~based~~in various ways focused on ~~learners exploring for themselves~~linking learner's explorations and experiences as they create valid arguments based on observations or data~~.~~ to reflective thinking. In other 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 ~~the~~these phases ~~supporting~~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 ~~the phenomena~~learning science, much has been done to include inquiry in curriculums and training science teachers in inquiry practices ~~and there~~. 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 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.~~



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.

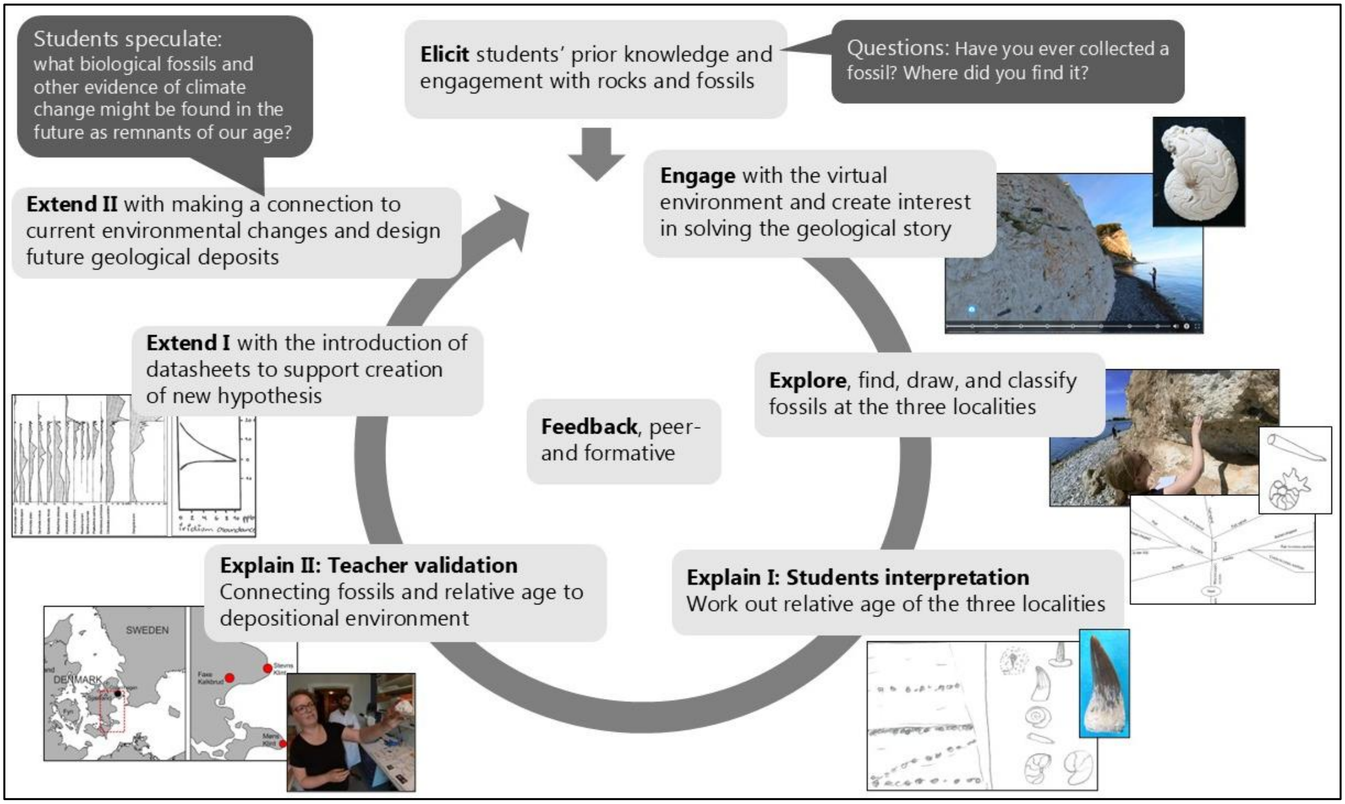


Figure 1: Overview of the inquiry phases of the lesson designed ~~as a multi-phase inquiry model~~ with *Elicit*: Students prior knowledge, *Engage*: Creating interest in working out the geological story, *Explore*: Students independent exploration, *Explain I*: Students interpretation, *Explain II*: Teacher validation and expansion, *Extend I*: Teacher introduces ~~data-sheets~~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 ~~an~~the end ~~to~~of a ~~science~~scientific investigation but a possible motivation to continue exploration. Feedback is placed in the middle, indicating that ~~the~~ students ~~as well as~~and the teacher ~~get~~both give and ~~provide~~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 it is in person, in the field, in the laboratory, or online, requires a range of skills, attitudes, and content knowledge that all need embeddingto 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 skills related to fieldwork skills. 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.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. 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: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 wrote the original draft; KRSH and LMM tested the lesson; JM and NRT provided the geological and palaeontological background for the project and reviewed and edited the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

Acknowledgements

The authors wish to thank the students who tested the teaching material for their enthusiasm and constructive feedback. Thanks to the reviewers who took the time to read and offer feedback to improve the manuscript.

References

Anderson, L. W. and Krathwohl, D. R. (Eds.): A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Abridged. New York, Longman, 2001.

Anderson, R. D.: Reforming Science Teaching: What Research Says About Inquiry. Journal of Science Teacher Education, 13(1), 1–12. https://doi.org/10.1023/A:1015171124982, 2002.

Bonali, F. L., Russo, E., Vitello, F., Antoniou, V., Marchese, F., Fallati, L., ... and Tibaldi, A.: How academics and the public experienced immersive virtual reality for geo-education. Geosciences, 12(1), 9, 2021.

Bond, C. E., and Cawood, A. J.: A role for Virtual Outcrop Models in Blended Learning: improved 3D thinking, positive perceptions of learning and the potential for greater equality, diversity and inclusivity in geoscience. Geoscience Communication Discussions, 2020, 1-20, 2020.

Bond, C. E., Pugsley, J. H., Kedar, L., Ledingham, S. R., Skupinska, M. Z., Gluzinski, T. K., and Boath, M. L.: Learning outcomes, learning support and cohort cohesion on a virtual field trip: an analysis of student and staff perceptions. Geoscience Communication Discussions, 5, 317-323, 2022.

Bybee, R. W.: The BSCS 5E instructional model and 21st century skills. Colorado Springs, Co: BSCS, 24, 2009.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N.: The BSCS 5E instructional model: Origins and effectiveness. Colorado Springs, Co: BSCS, 5(88-98), 2006.

Cawood, A., and Bond, C.: eRock: An open- access repository of virtual outcrops for geoscience education. GSA Today, v. 29, p. 36– 37, 2019.

Cliffe, A. D.: A review of the benefits and drawbacks to virtual field guides in today's Geoscience higher education environment. International Journal of Educational Technology in Higher Education, 14(1), 28, 2017.

Dewey, J.: How we think. Heath, Boston, 1933.

Dolphin, G., Dutchak, A., Karchewski, B., and Cooper, J.: Virtual field experiences in introductory geology: Addressing a capacity problem, but finding a pedagogical one. Journal of Geoscience Education, 67(2), 114-130, 2019.

El-Mowafy, A.: Using peer assessment of fieldwork to enhance students' practical training. Assessment & Evaluation in Higher Education, 39(2), 223-241, 2014.

Eisenkraft, A.: Expanding the 5E model. The Science Teacher, 70(6), 56-59, 2003.
Elkins, J. T., and Elkins, N. M.: Teaching geology in the field: Significant geoscience concept gains in entirely field-based introductory geology courses. Journal of geoscience education, 55(2), 126-132, 2007.
Engel, K. T., Davidson, J., Jolley, A., Kennedy, B., and Nichols, A. R. L.: Development of a virtual microscope with integrated feedback for blended geology labs. Journal of Geoscience Education, 72(4), 367–381. https://doi.org/10.1080/10899995.2023.2202285, 2023.
Evelpidou, N., Karkani, A., Komi, A., Giannikopoulou, A., Tzouxanioti, M., Saitis, G., Spyrou, E., & Gatou, M.-A.: GIS-Based Virtual Field Trip as a Tool for Remote Education. Geosciences, 12(9), 327, 2022.
Foley, K., Petcovic, H. L., and Semken, S.: How college geoscience instructors report finding and implementing virtual field experiences for their courses. Journal of Geoscience Education, 72(4), 450–462. https://doi.org/10.1080/10899995.2024.2334179, 2024.
Furtak, E. M., Seidel, T., Iverson, H., and Briggs, D. C.: Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. Review of educational research, 82(3), 300-329, 2012.
Granshaw, F., and Duggan-Haas, D.: Virtual fieldwork in geoscience teacher education: Issues, techniques and models, in: Google earth and virtual visualizations in geoscience education and research, edited by: Whitmeyer, S, Bailey, J. E., De Paor, D. G., and Ornduff, T., Geological Society of America, 285–303, 2012.
Guillaume, L., Laurent, V., and Genge, M. J.: Immersive and interactive three-dimensional virtual fieldwork: Assessing the student learning experience and value to improve inclusivity of geosciences degrees. Journal of Geoscience Education, 71(4), 462-475, 2023.
Herodotou, C., Muirhead, D. K., Aristeidou, M., Hole, M. J., Kelley, S., Scanlon, E., and Duffy, M.: Blended and online learning: a comparative study of virtual microscopy in Higher Education. Interactive Learning Environments, 28(6), 713-728, 2020.
Heiss, E.D., Obourn, E.S., and Hoffman, C.W.: Modern Science Teaching, New York: Macmillan, 1950.
Houghton, J. J., Lloyd, G. E., Robinson, A., Gordon, C. E., and Morgan, D. J.: The Virtual Worlds Project: geological mapping and field skills. Geology Today, 31(6), 227-231, 2015.
Hurrell, E. R., Hutchinson, S. M., Yorke, L., Batty, L. C., Bunting, M. J., Swanton, D., ... and Parsons, D. R.: The role of virtual field trips in Geography higher education: A perspective paper. Area, e70011, 2025.
Hurst, S.: Use of “virtual” field trips in teaching introductory geology. Computers & Geosciences, 24(7), 653–658. https://doi.org/10.1016/S0098-3004(98)00043-0, 1998.
Jeffery, A. J., Rogers, S. L., Jeffery, K. L., and Hobson, L.: A Flexible, Open and Interactive Digital Platform to Support Online and Blended Experiential Learning Environments: Thinglink and thin sections. Geoscience Communication Discussions, 2020, 1-27, 2020.
Jolley, A., Kennedy, B. M., Brogt, E., Hampton, S. J., and Fraser, L.: Are we there yet? Sense of place and the student experience on roadside and situated geology field trips. Geosphere, 14(2), 651-667, 2018.

Karplus, R., and Their, H. D.: A new look at elementary school science, new trends in curriculum and instruction series. Chicago: Rand McNally and Co., 1967.

Kennedy, B., Engel, K., Davidson, J., Tapuke, S., Hikuroa, D., Martin, T., and Zaka, P.: Incorporating science communication and bicultural knowledge in teaching a blended volcanology course, EGUsphere [preprint],Geosci. Commun., 8, 107–124, https://doi.org/10.5194/egusphere-2024-2512, 14 August 2024. gc-8-107-2025, 2025.

Klippel, A., Zhao, J., Oprean, D., Wallgrün, J. O., Stubbs, C., La Femina, P., and Jackson, K. L.: The value of being there: Toward a science of immersive virtual field trips. Virtual Reality, 24, 753-770, 2020.

Kolb, D.: Experiential learning: Experience as the source of learning and development. New Jersey: Prentice-Hall., 1984.

Kolbert, E.: The sixth extinction: An unnatural history. Henry Holt and Company, 2014.

Madsen, L. M., Evans, R., and Bruun, J.: Inquiry-based teaching: The 6F model - its origin and development in Denmark [Undersøgelsesbaseret undervisning: 6F-modellen - dens tilblivelse og udvikling i Danmark]. MONA, 1, 26–45, 2020.

Madsen, L. M., Evans, R., and Malm, R. H.: Using a Wicked Problem for Inquiry-Based Fieldwork in High School Geology: Addressing Climate Change and Mass Extinction Events, in: Addressing Wicked Problems through Science Education: The Role of Out-of-School Experiences, edited by: Dillon, J., Achiam, M., and Glackin, M. Springer, 167–188, 2021.

Malm, R. H., Madsen, L. M., and Lundmark, A. M.: Students' negotiations of belonging in geoscience: Experiences of faculty–student interactions when entering university. Journal of Geography in Higher Education, 44(4), 532-549, 2020.

Minner, D. D., Levy, A. J., and Century, J.: Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 47(4), 474-496, 2010.

Mogk, D. W., and Goodwin, C.: Learning in the field: Synthesis of research on thinking and learning in the geosciences, in: Earth and mind II: A synthesis of research on thinking and learning in the geosciences, edited by: Kastens, K. A. and Manduca, C. A., (Vol. 2, pp. 131–164) Special Paper 486. The Geological Society of America, 2012.

Nyarko, S. C., and Petcovic, H. L.: Do students develop teamwork skills during geoscience fieldwork? A case study of a hydrogeology field course. Journal of Geoscience Education, 71(2), 145-157, 2023.

Posselt, J. R., and Nuñez, A. M.: Learning in the wild: Fieldwork, gender, and the social construction of disciplinary culture. The Journal of Higher Education, 93(2), 163-194, 2022.

Pugsley, J. H., Howell, J. A., Hartley, A., Buckley, S. J., Brackenridge, R., Schofield, N., ... and Vanbiervliet, J.: Virtual field trips utilizing virtual outcrop: construction, delivery and implications for the future. Geoscience Communication, 5(3), 227-249, 2022.

Rojas-Sánchez, M. A., Palos-Sánchez, P. R., and Folgado-Fernández, J. A.: Systematic literature review and bibliometric analysis on virtual reality and education. Education and Information Technologies, 28(1), 155-192, 2023.

Rönnebeck, S., Bernholt, S., and Ropohl, M.: Searching for a common ground–A literature review of empirical research on scientific inquiry activities. Studies in science education, 52(2), 161-197, 2016.

Saha, S., Tapuke, S., Kennedy, B., Tolbert, S., Tapuke, K., Macfarlane, A., ... and Smith, B.: A place-based virtual field trip resource that reflects understandings from multiple knowledge systems for volcano hazard education in Aotearoa NZ: Lessons from collaborations between Māori and non-Māori. Journal of Geoscience Education, 71(3), 388-402, 2023.

Senger, K., Betlem, P., Birchall, T., Buckley, S. J., Coakley, B., Eide, C. H., Flaig, P. P., Forien, M., Galland, O., Gonzaga, L., Jensen, M., Kurz, T., Lecomte, I., Mair, K., Malm, R. H., Mulrooney, M., Naumann, N., Nordmo, I., Nolde, N., ... Smyrak-Sikora, A.: Using digital outcrops to make the high Arctic more accessible through the Svalbox database. Journal of Geoscience Education, 69(2), 123-137. https://doi.org/10.1080/10899995.2020.1813865, 2021.

Stokes, A., and Boyle, A. P.: The undergraduate geoscience fieldwork experience: Influencing factors and implications for learning, in: Field geology education: Historical perspectives and modern approaches, edited by: Whitmeyer, S. J., Mogk, D. W., and Pyle, E. J. (Vol. 461, p. 291). Special Paper 461. The Geological Society of America, 2009.

Watson, A., Kennedy, B. M., Jolley, A., Davidson, J., and Brogt, E.: Design, implementation, and insights from a volcanology Virtual Field Trip to Iceland. Volcanica, 5(2), 451–467. https://doi.org/10.30909/vol.05.02.451467, 2022.

Watson, A., Kennedy, B. M., Davidson, J., Brogt, E., and Jolley, A.: The implementation of a virtual field trip to aid geological interpretation within an undergraduate volcanology course. Journal of Geoscience Education, 1-13, 2023.

Whitmeyer, S. J., and Dordevic, M.: Creating virtual geologic mapping exercises in a changing world. Geosphere, 17(1), 226-243, 2021.