Digital Field Representations as a Holistic Approach to Experiential Learning in High Arctic Geoscience Field Education

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Abstract. Field-based education is a cornerstone of geoscience learning, offering students the opportunity to connect theoretical knowledge with real-world geological contexts. Yet access to such experiences remains limited due to logistical, financial, environmental, and social barriers, especially in remote or extreme environments like the High Arctic. These barriers may be especially salient for people with disabilities. In response to these challenges, Virtual Field Experiences (VFEs) are emerging as promising tools to complement traditional fieldwork. In this study we investigate how VFEs contribute to experiential learning among students at the University Centre in Svalbard (UNIS) in Longyearbyen, Svalbard.

Using a mixed-methods approach grounded in experiential learning theory and the Technology Acceptance Model, we surveyed 66 students who used VFEs as part of geoscience courses at UNIS before and after physical field excursions. Results reveal that students found VFEs particularly valuable for pre-field orientation, spatial awareness, and post-field reflection. Students reported improved readiness, deeper conceptual understanding, and enhanced engagement. The virtual representations enabled them to revisit complex sites, identify overlooked features, and consolidate observations made during fieldwork. Importantly, most participants did not see VFEs as a replacement for traditional fieldwork but recognized their role in making field learning more inclusive, repeatable, and accessible.

We highlight how VFEs may help students manage perceived novelty by familiarizing them with unfamiliar environments before initial field exposure. Students expressed strong interest in broader applications of VFEs across courses and disciplines, particularly when enriched with interactivity and guided tasks. These findings suggest that digital field representations hold significant promise for expanding access to geoscience education and perceived reinforcement of understanding. Future research should explore co-design practices with students and educators to optimize VFEs for equity, sustainability, and pedagogical impact across diverse learning environments.

1 Introduction

Field education, or field-based learning, is a cornerstone of geoscience education, enabling students to connect theoretical knowledge with practical skills (e.g., Lonergan & Andresen, 1988). This experiential approach is crucial not only for the development of disciplinary identities, but also for fostering social cohesion among students and educators in the field (Malm, 2020). Despite the established importance of hands-on field-based learning, advances in technology have led to the increased use of VFEs (Bond and Cawood, 2020; Horota et al., 2022; Pugsley et al., 2024). The Covid-19 pandemic with severe restrictions on field-based learning greatly accelerated this development (Senger et al., 2021). These tools are reshaping expectations for skill development among geoscience educators, offering new ways for learning (e.g., Evelpidou et al., 2021; Pugsley et al., 2021; Horota et al., 2023).

In geoscience education, fieldwork is frequently perceived as the pinnacle of education, the most meaningful and valued aspect of study programs. As a result, it can sometimes be difficult to raise and grapple with the challenges with, and barriers to, engaging in learning in the field (Malm et al., 2020; Marín-Spiotta et al., 2020; Nuñez et al., 2021). Field education has, for instance, been criticized for its inaccessibility to people with disabilities (Feig et al., 2019; Mol & Atchison, 2019; Stokes et al., 2019). Furthermore, alternatives to field-based learning have typically been limited and of poor quality (Carabajal et al., 2017). It has also been criticized for its overvaluing of masculinity (e.g., demonstrations of strength/speed as signals of competence), often resulting in obstacles for women, transgender and non-binary people to contribute to and find a place in the disciplinary culture of geosciences (Heimann & Johansson, 2024). Moreover, issues of safety related to differences in sexuality, gender, race, and gender identity may be inadequately addressed, resulting in student and staff amending their own activities due to perceived risks (e.g., avoiding drinking, staying with other women to avoid sexual harassment or violence) (Stokes et al., 2015; Nuñez et al., 2021; Mattheis et al., 2022; Posselt & Nuñez, 2022). Furthermore, the costs associated with field education also act as a barrier for students and institutions alike (Giles et al., 2020; Metzger, 2024). This is especially the case for students and institutions in the global south where budgets of geoscience educational institutions are lower than the global average. Finally, the environmental consequences of travel, in particular air travel, have caused many geoscientists to weigh the benefits of learning in the field, with the potential impact of these activities (Pugsley et al., 2024).

In considering the challenges and barriers of field-based learning, the possibilities and potential of technology to broaden participation and accessibility warrants renewed consideration. Of particular interest has been the growth and development of digital tools, their use as supplementary/alternative pedagogical resources for geoscience teaching, and the possibility for widening access for field-based learning (e.g., Feig et al., 2019; Moysey & Lazar, 2019; Whitmeyer et al., 2020; Bonali et al., 2021; Pugsley et al., 2021). Cliffe (2017) acknowledged VFEs as invaluable assets in geoscience education, offering inclusivity, skill-building opportunities, and cost-effectiveness. They complement rather than replace fieldwork, providing scalability, repeatability, and physical safety (Stott et al., 2014). Early use of VFEs and alternative assessments has been criticized as poorly developed and inadequate substitutes for fieldwork (for example, when offered to students with disabilities who may encounter barriers to participation) (Carabajal et al., 2017). The quality of VFEs continues to improve. Mead et al.

(2019) highlights the significant improvement in meeting student learning outcomes with interactive VFEs that feature adaptive feedback mechanisms. These digital resources engage students actively, enable multiple means of engagement (a core universal design for learning principles) and fosters deeper comprehension and retention of geological concepts (Hassan et al., 2019; Bimba et al., 2021). Importantly, Hay et al. (2013) offers a valuable theoretical framework to support the integration of VFEs, emphasizing their role in providing authentic learning experiences by contextualizing theoretical knowledge within realistic geological scenarios. Despite documented skepticism among some geoscientists regarding its pedagogical value (e.g., Cliffe, 2017; Dolphin et al., 2019), VFEs represent a transformative approach in geoscience education, making possible expanded and improved accessibility, more varied means of meeting learning outcomes, and a bridge to link to abstract concepts and real-world applications.

Several studies report on students' experiences with VFEs in geoscience education. Guillaume et al. (2023) found that students generally liked virtual fieldwork but missed being outdoors and socializing. Cliffe (2017) discuss how VFEs can be helpful by making learning more inclusive and engaging but also mentioned difficulties in making VFEs. Suthren (1998) and Dolphin et al. (2019) changed perspectives looking into the virtual experiences broadly. Suthren (1998) focused on using computers in geoscience classes, while Dolphin et al. (2019) suggested that we need to change how we teach geology. What these studies demonstrate is that VFEs can be powerful learning resources, in particular when educators support students' use and integrate and connect these tools with existing field teaching activities. VFEs are not a 'cure-all' but an enriching tool for student learning. However, significantly more research is needed to query how these tools can be used well and how prepared students and teachers are for the integration of VFEs into conventional curriculum.

Rather than engaging in a debate about investigating if VFEs should hold a place in geoscience education, or how effective they can be, this paper considers how and in what ways digital field representations can act alongside conventional field-based teaching activities to support student learning. Given the growth of digital tools in geoscience education, and the growing need for more accessible, varied and sustainable means of engaging in field teaching, we must better understand how prepared students are and how they perceive and use digital tools in relation to their learning.

To investigate how students engage with digital field representations, this study focuses on the VR Svalbard platform, an interactive, web-based system developed at the University Centre in Svalbard (UNIS) as part of the Svalbox initiative (Senger et al., 2021). VR Svalbard integrates drone-based photogrammetry, photospheres, maps, and 3D terrain data to produce VFEs across Svalbard. These VFEs are structured as Virtual Field Guides (VFGs) and Virtual Field Tours (VFTs), enabling users to explore Arctic field sites remotely. As the digital infrastructure underlying this study, VR Svalbard serves as both a research tool and a pedagogical intervention, offering a scalable and inclusive model for enhancing field-based geoscience learning.

To conceptually frame how digital tools may support field-based learning, we draw on Kolb's Experiential Learning Theory (ELT), which conceptualizes learning as a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). In geoscience field education, these stages typically unfold through in situ observation, reflection, interpretation, and iterative testing of geological ideas. We use ELT as a theoretical lens to examine how VFEs may scaffold different stages of this cycle before, during, and after physical fieldwork.

A related concept particularly relevant to field-based education is “novelty space,” which describes the cognitive and affective demands associated with encountering unfamiliar environments (Stainfield et al., 2000; Boyle et al., 2007). In remote and complex settings such as the High Arctic, environmental unfamiliarity, logistical constraints, and sensory overload may compete with disciplinary learning goals. Managing novelty space does not eliminate the experiential richness of fieldwork but may redistribute cognitive resources toward observation, interpretation, and reflection. In this study, we examine whether VFEs contribute to reducing perceived novelty and supporting more aligned experiential learning processes.

Hence, in this paper we address two research questions: 1) How do students perceive the usefulness of digital field representations in their geoscientific field learning experiences? 2) How do digital field representations contribute to managing the novelty space in learning environments according to students' perspectives?

1.1 Virtual Field Experiences in the context of Experiential Learning Theory

Building on the theoretical framing introduced above, VFEs can be understood as tools that scaffold multiple stages of the experiential learning cycle. In geoscience field education, learning often unfolds through direct observation in the field (concrete experience), followed by reflection, interpretation, and the development of conceptual models (reflective observation and abstract conceptualization), which are then tested through further field engagement (active experimentation).

Figure 1: The Experiential Learning Theory of Kolb (1984) represented as a four-stage cycle adapted for geoscience field-based learning with Virtual Field Experiences. The four ELT stages, figure labels, arrows, schematic structure, and pedagogical interpretation were created and manually edited by the authors. Only the background illustrative images were generated using

ChatGPT with DALL·E. These images were generated separately, based on author-provided reference material and stage-specific prompts designed to visually represent different moments in the experiential learning cycle, including field preparation, field observation, post-field reflection, and reinterpretation using digital field tools. Prompts are provided in the Acknowledgements. The AI-generated background images are used only as conceptual illustrations and do not represent empirical data, actual students, field observations, or specific Svalbard localities.

Recent advances in digital geoscience, including digital outcrop models (DOMs), photospheres, photogrammetric reconstructions, and GIS-based visualization tools (e.g., Westoby et al., 2012; Howell et al., 2014; Horota et al., 2024), have expanded the ways in which these stages can be supported. VFEs allow students to preview field environments, revisit complex sites, and examine geological features at multiple scales. In this way, they may support anticipatory conceptualization before fieldwork, structured reflection after field experiences, and iterative reinterpretation across time and space (Figure 1).
Rather than functioning as replacements for physical fieldwork, VFEs may extend experiential learning processes beyond the temporal and logistical constraints of in situ teaching. The extent to which students perceive these tools as supporting their experiential learning is explored in the Results and Discussion sections.

2 Svalbard – year-round geoscience teaching

To situate this investigation within its specific educational context, we briefly describe the Arctic field environment and institutional setting in which the digital field representations were implemented.
This study focusses on UNIS, an educational institution located in the Norwegian Arctic Archipelago of Svalbard (74-81ºN), situated between mainland Norway and the North Pole (Figure 2). Svalbard is renowned for its dramatic landscapes, geologically diverse terrain and a rich history of natural resource exploration and exploitation (e.g., Senger et al., 2021, 2025). The region's geological record spans over 1 billion years, capturing evidence of past orogenies, glaciations, climate change, and magmatic events, making it an exceptional natural laboratory for geoscientific research and teaching. Svalbard's main settlement, Longyearbyen (population 2500), located at a high-latitude position offers a unique setting to study sedimentary basins, deep-time paleoclimate, and tectono-magmatic events (Olaussen et al., 2025). This geological richness, combined with its accessibility during summer months, has cemented Svalbard's status as a great site for geoscientific related field-based education and research.
In this context, UNIS delivers Arctic education and research throughout the highly seasonal polar year that includes a four month long polar night. It integrates field-based learning into its curricula, providing students with opportunities to conduct hands-on studies in a remote Arctic environment fostering international collaboration and attracting students and researchers from across the globe. Its focus on experiential learning aligns with modern pedagogical approaches, emphasizing data collection, interpretation, and field safety in extreme conditions (e.g., Senger et al., 2021, 2025).

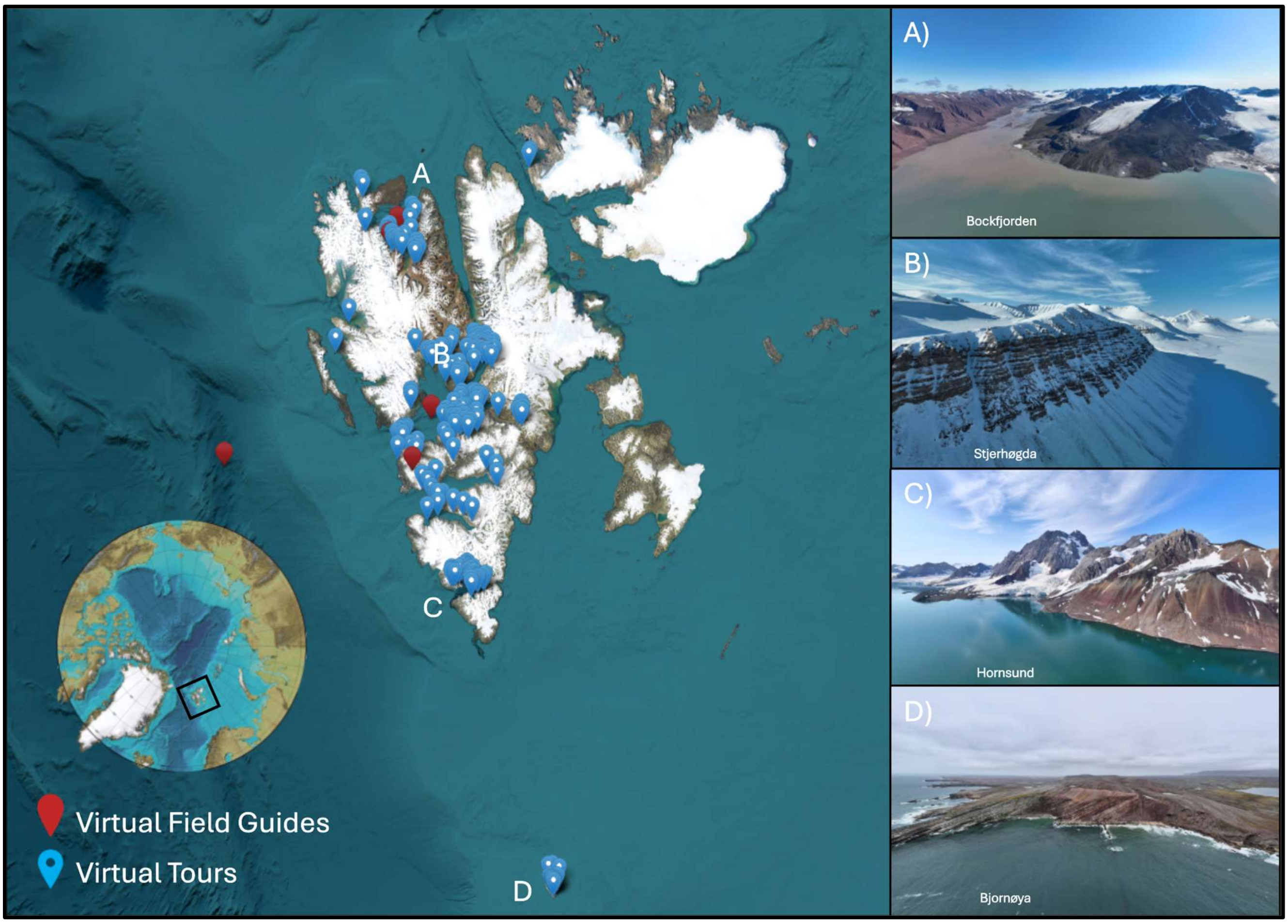


Figure 2: Location of the Svalbard archipelago (black box on inset map, based on IBCAO; Jakobsson et al., 2008) displaying markers of available Virtual Field Guides (red, n=6) and Virtual Field Tours (blue, n= 175) from www.vrsvalbard.com/map. Images A, B, C, and D show the geological diversity of Svalbard's landscapes.

The VR Svalbard platform (Horota et al., 2024) represents a paradigm change to Arctic field education by integrating VFEs into geoscience learning. Developed as part of the UNIS-led Svalbox initiative (Senger et al., 2021; Betlem et al., 2023), VR Svalbard combines high-resolution drone imagery (photogrammetry and derived datasets, photospheres, map layers, etc.) to create VFEs through VFGs and VFT (Figure 3). These tools enable students and researchers to digitally explore remote Arctic landscapes, fostering accessibility and inclusivity while complementing physical fieldwork. This platform supports experiential learning by simulating field excursions, allowing users to investigate geomorphological and structural features, characterize geological features (e.g., orientation, bed thickness), and analyse spatial relationships. This integration of digital tools reflects a broader movement toward hybrid teaching methodologies, ensuring the sustainability and scalability of Arctic field education in a changing climate.

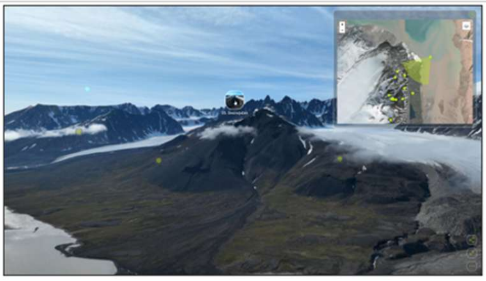
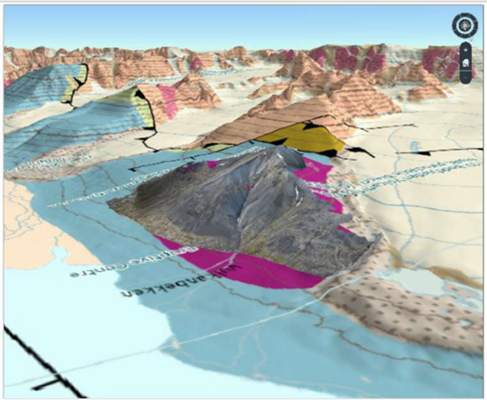
		Digital Field Representations							Example
Virtual Field Experiences	**Description**	*Digital outcrop models*	*Photospheres*	*Digital elevation models*	*Orthomosaics*	*Map layers*	*Tile map services*	*3D globe*	
Virtual Field Tours	Transitions between drone-based photosphere that allows users to navigate through virtual landscapes.	■	■			■	■		
Virtual Field Guides	Thematic field guides focused on geological contexts. Detailed visualizations and data integration in 3D environment.	■		■	■	■	■	■	

Figure 3: Overview of VR Svalbard Virtual Field Experiences and Digital Field Representations.

3 Data and Methods

3.1 Research design

This research design was structured around the two research questions introduced in Section 1. Research Question 1 (RQ1), concerning students' perceptions of the usefulness of VFEs, was addressed through the Technology Acceptance Model (TAM) instrument and post-field educational impact items (Appendix A1). Research Question 2 (RQ2), concerning the management of novelty space, was examined primarily through pre-field preparedness items and post-field reflective responses (Appendix B1).

To address these questions, we adopted a mixed-methods approach to evaluate the integration of VFEs from the VR Svalbard platform into geoscience education at UNIS. The design focused on students' engagement with VFEs, their perceived educational value, and their reflections before and after physical fieldwork. Two key objectives guided the analysis: first, to evaluate technological readiness and perceived usability using TAM; and second, to assess students perceived learning support and preparedness through structured survey instruments.

3.2 Survey Instruments

To investigate students' perceptions of digital field representations, a structured questionnaire combining Likert-scale items and open-ended responses was developed for this study. The study employed three interconnected survey components:

1. **Technology Acceptance Model (TAM) survey**
   The TAM component assessed Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Behavioral Intention (BI) using items adapted from Davis (1989) and Venkatesh and Bala (2008), contextualized for digital field representations. Responses were recorded on a 7-point Likert scale (1 = strongly disagree; 7 = strongly agree).
2. **Pre-field educational impact survey**
   This component evaluated students' perceived preparedness, geographic orientation, and anticipatory engagement prior to physical field excursions. Responses were recorded on a 5-point Likert scale (1 = fully disagree; 5 = fully agree). These items were designed to examine perceived familiarity with the field environment and were conceptually linked to the management of novelty space.
3. **Post-field educational impact survey**
   The post-field section assessed students' reflections on how VFEs supported their learning after fieldwork. Items addressed perceived reinforcement of observations, spatial integration across scales, and consolidation of understanding. Responses were recorded on a 5-point Likert scale (1 = fully disagree; 5 = fully agree). These items were conceptually aligned with reflective stages of experiential learning.

The survey components were distributed at two distinct time points. The pre-field instrument was administered after students had engaged with VFEs but prior to the physical field excursion. The post-field instrument was distributed following completion of field activities. The TAM component was administered after students had sufficient exposure to the VR Svalbard platform to evaluate its usability and usefulness.

Together, these instruments enabled examination of technological acceptance (RQ1), perceived educational support (RQ1), and perceived management of novelty space (RQ2), while allowing interpretation through the lens of Experiential Learning Theory.

3.3 Study participants and data collection instruments

A total of 131 students enrolled in relevant UNIS courses were invited to participate. Sixty-nine students consented to participation, and 66 completed the main survey components. Of these:

- 54 respondents completed the TAM section,
- 41 completed pre-field preparedness items,
- 52 completed post-field reflection items.

Variation in response numbers reflects differences in course timing and the voluntary nature of specific survey components.

Research Question	Survey Component	Scale	Respondents (N)	Analytical Theme (Section 4)
RQ1 – Perceived usefulness	TAM survey	1–7	54	4.2 Technology acceptance
RQ1 – Educational support	Post-field survey	1–5	52	4.2 Educational impact
RQ2 – Novelty space	Pre-field survey	1–5	41	4.2 Pre-field experiences
Usage patterns	Engagement survey	Mixed	66	4.1 Usage patterns

Table 1: Overview of Research Design and Analytical Structure

The study involved 131 students attending bachelor's, master's, and PhD-level courses at UNIS (Table 2). Participants were selected based on their participation in field-based courses at UNIS that incorporated VFEs into their curriculum. These courses span a range of topics, ensuring a sample representative of various subfields within geoscience and polar meteorology (Table 2). Participants provided informed consent and were briefed on the study's objectives and data collection processes.

The selection of UNIS courses allowed the study to target students with significant exposure to Arctic fieldwork, offering a unique context in which to evaluate the integration of VFEs into traditional field education.

Course Code	Title	Year	Number of students	VR Svalbard usage in course activities	ECTS	Level
AGF-213	Polar Meteorology and Climate	2024	16	DTL, FP, ON, H&S, PFA, and AA.	15	Bachelor
AGF-350/850	The Arctic Atmospheric Boundary Layer and Local Climate Processes	2024	19	DTL, FP, ON, H&S, PFA, and AA.	10	Masters/PhD
AG-209	The Tectonic and Sedimentary History of Svalbard	2024	15	DTL, FP, H&S, GVA, PFA, AA, and STP.	15	Bachelor

AG-222	Integrated Geological Methods: From Outcrop to Geomodel	2024	(Same as AG-209)	DTL, FP, H&S, GVA, PFA, AA, and STP.	15	Bachelor
AG-210	Quaternary and Glacial Geology of Svalbard	2023	17	DTL, ON, DCL, FP, H&S, GVA, PFA, AA, and STP.	15	Bachelor
AG-220	Environmental Change in the high Arctic Landscape of Svalbard	2023	20	DTL, ON, DCL, FP, H&S, GVA, PFA, AA, and STP.	10	Bachelor
AG-336/836	Rift Basin Reservoirs: From Outcrop to Model	2024	15	DTL, FP, H&S, GVA, PFA, AA, and STP.	10	Masters/PhD
AG-351/851	Arctic Tectonics and Volcanism	2024	14	DTL, FP, H&S, GVA, PFA, AA, and STP.	10	Masters/PhD
TOTAL			131			

Table 2: Number of students from Arctic geology and Arctic geophysics courses, integration of VR Svalbard Virtual Field Environments, course-Levels and educational value. Note that the courses AG-209 and AG-222 are run in parallel with the same students. ECTS = European Credit Transfer System. *DTL: Demonstration Tool in Lectures, FP: Fieldwork Planning, ON: Orientation and Navigation, H&S: Health and Safety Briefings, GVA: Guaranteed Virtual Field Access (to field sites in daylight and good visibility), DCL: Detecting Changes in the Landscape, PFA: Post-Fieldwork Analysis, AA: Assessments and Activities, STP: Students' Term Projects. ECTS = European Credit Transfer System (60 ECTS = 1 year of full-time study).

4 Results

The results are structured to address the two research questions. Section 4.1 presents patterns of student engagement with the VR Svalbard platform. Section 4.2 addresses Research Question 1 by examining students' perceptions of usefulness and ease of use through the Technology Acceptance Model (TAM). Section 4.3 addresses both Research Question 1 and Research Question 2 by analysing students perceived educational impact of VFEs before and after fieldwork, interpreted through the lenses of Experiential Learning Theory (ELT) and the concept of novelty space. Together, these themes provide an integrated view of technological acceptance, experiential support, and perceived preparedness in Arctic field-based geoscience education.

4.1 Usage patterns

The survey data reveal significant engagement with the VR Svalbard platform among participants. Of the 66 students who completed the survey, 86% reported having used the platform at least once. The use of VFEs was integrated into several contexts, demonstrating its broad applicability within field-based education. Notably, 71% of respondents used the VFEs during field preparation lectures, while 55% used them as part of post-fieldwork exercises. Additionally, 53% of students engaged with the platform independently out of personal curiosity, showing a high degree of self-motivated exploration (Figure 4).

Beyond course-integrated use, students also employed the tool for planning their own fieldwork (38%), revisiting specific field localities (53%), and extracting visual data for assignments or term projects (38%). This range of uses emphasizes the platform's flexibility in serving various pedagogical and research needs.

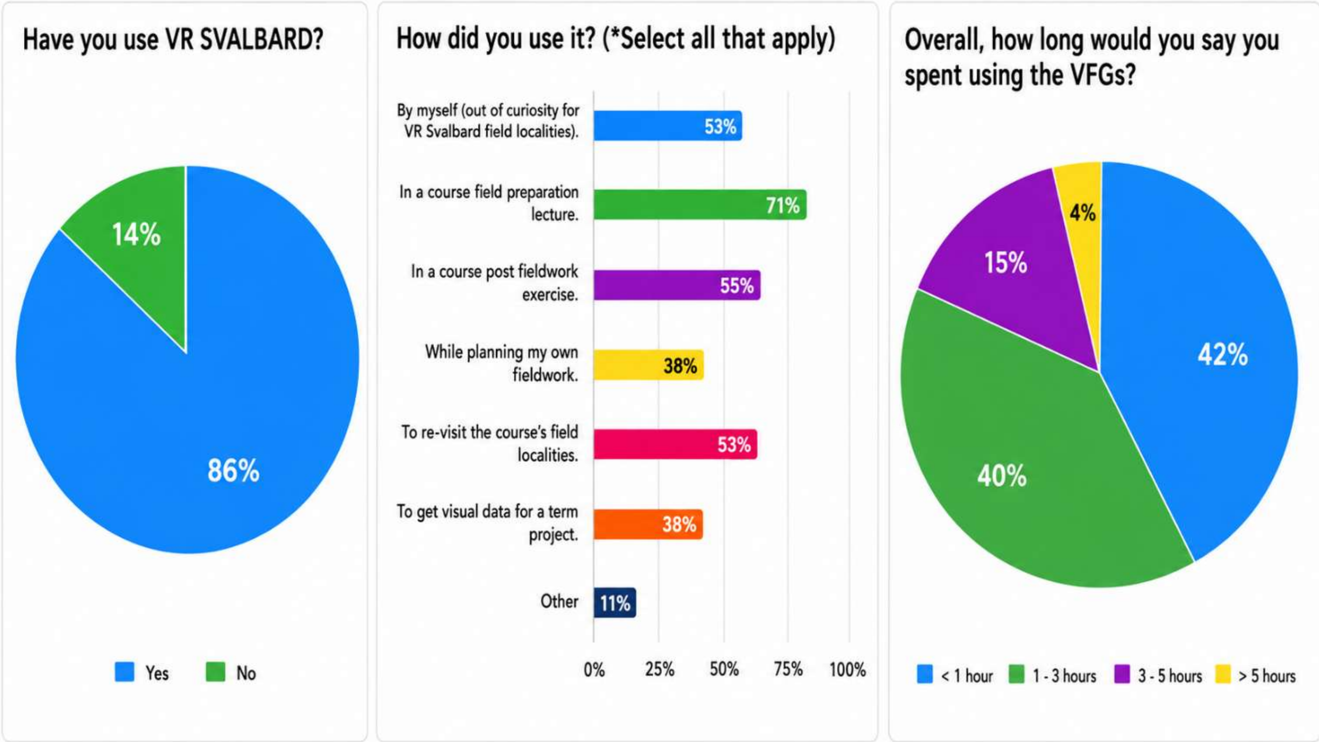


Figure 4: Usage Patterns of VR Svalbard: Engagement, Contexts of Use, and Time Spent on VFEs.

In terms of time spent, 42% of users reported engaging with the platform for less than one hour, 40% for one to three hours, 15% for three to five hours, and 4% for over five hours. These time ranges likely reflect the one-hour session typically allocated in class for VR Svalbard activities. However, it is especially encouraging to observe that more than half of students used the platform beyond the scheduled class time. This suggests that many students engaged with the platform beyond scheduled sessions, suggesting its effectiveness not only as a classroom tool but also as a meaningful extension of field learning. These engagement patterns indicate that VFEs were used both as structured instructional tools and as optional self-directed resources.

4.2 Technology acceptance model

The evaluation of VR Svalbard's VFEs technical aspects was conducted using a TAM questionnaire. Respondents were asked to rate their agreement with statements addressing these aspects on a 7-point Likert scale. The dataset included responses from 54 participants who completed this section of the questionnaire.

Students rated the platform highly in terms of perceived usefulness. The highest-scoring items were "Using VR Svalbard would enhance my effectiveness in the field" and "I would find VR Svalbard useful in my field learning activity," each with a mean score of 6.0. These high ratings underscore students' belief that the platform positively contributes to their learning outcomes. Other positively rated items included the platform's ability to help complete field tasks more quickly and efficiently.

Perceived Ease of Use statements also scored well, with statements such as "Learning to operate VR Svalbard would be easy for me" and "My interaction with VR Svalbard would be clear and understandable" both receiving mean scores around 5.9 (Figure 5). Although students generally found the platform intuitive, slightly lower ratings were given for items related to flexibility and user control, suggesting opportunities for improvement in the interface and customization features.

Behavioral Intention responses indicated that students were likely to continue using the platform. Statements such as "I would recommend VR Svalbard to my peers" and "I would use VR Svalbard for future field activities" received high scores, reflecting a strong willingness among students to engage with the tool beyond a single course context (Figure 5). This finding is particularly significant, as it suggests the long-term adoption of VR Svalbard as a resource for students. Moreover, it indicates that students are not only receptive to technology but may also serve as advocates for its broader implementation within geoscience curricula.

Together, the high ratings across Perceived Usefulness, Perceived Ease of Use, and Behavioral Intention suggest that VR Svalbard meets key criteria for technology acceptance in educational settings. The platform was perceived as a useful, easy-to-learn tool that students intend to continue using, an important foundation for promoting digital literacy and innovation in field-based geoscience education. However, the slightly lower ratings related to control and flexibility indicate areas for design improvement, particularly in refining user experience to better support a variety of learning preferences and workflows.

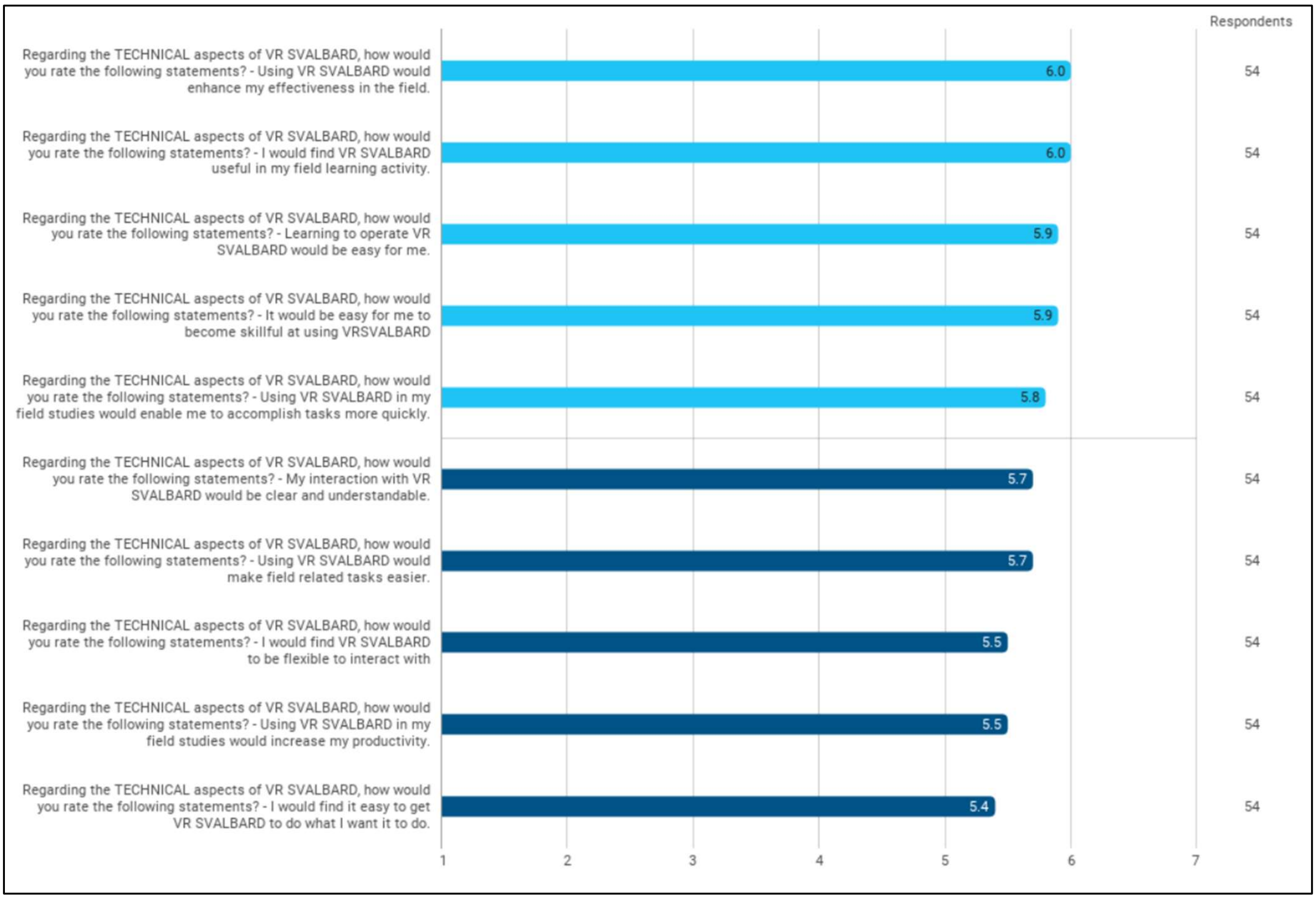


Figure 5: Likert plots of responses (n= 54), all starting with "Regarding the technical aspects of VR Svalbard, how would you rate the following statements?".

4.3 Perceived educational impact

To interpret how VFEs supported experiential learning processes, Likert-scale responses were grouped according to their alignment with stages of Kolb's experiential learning cycle (Kolb, 1984) and examined alongside the concept of novelty space. This subsection presents an analysis of how students perceived the educational value of VFEs in relation to their geoscience learning. Drawing on quantitative Likert-scale responses and qualitative open-ended comments from Appendix B1, the findings highlight how the integration of VFEs before and after field activities influenced student engagement, spatial awareness, immersion, preparedness, and perceived learning outcomes (Figure 6). These themes are further substantiated by the full distribution of responses presented in Figure 6, which provides a more nuanced view of how students positioned themselves. This scale allowed students to express varying degrees of agreement with statements about their experiences with the VFEs.

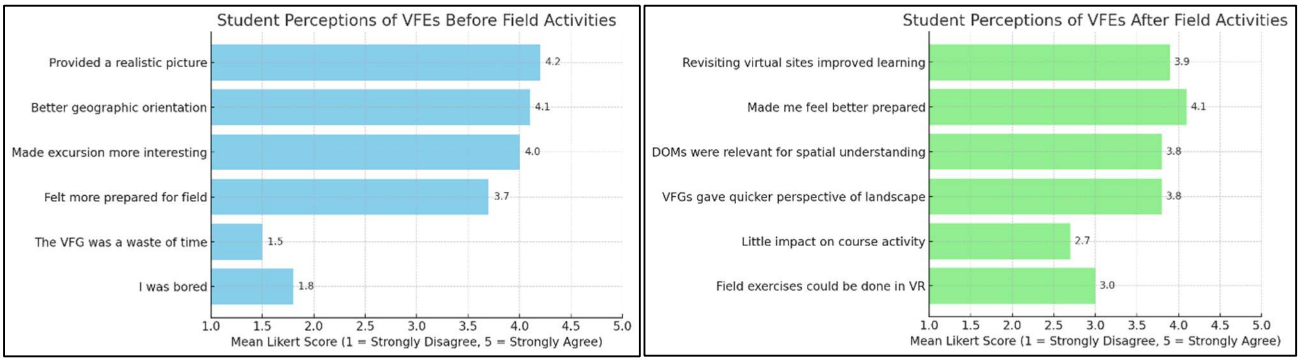


Figure 6: Mean Likert-scale responses (1 = strongly disagree, 5 = strongly agree) to selected statements about student perceptions of Virtual Field Experiences (VFEs) using VR Svalbard. The left panel shows responses before field activities, emphasizing the perceived realism, geographic orientation, and preparatory value of the VFGs. The right panel shows responses after field activities, highlighting how students reflected on the VFGs' role in reinforcing learning, spatial understanding, and field preparation. Results are based on 41 (pre-field) and 52 (post-field) respondents, respectively.

VR Svalbard was introduced into courses through a structured, two-phase integration strategy: pre-field and post-field activities. This deliberate inclusion aimed to optimize learning outcomes by scaffolding students' engagement with geoscientific content.

In the pre-field phase, instructors used VR Svalbard to orient students to Arctic landscapes and specific field locations. Activities included navigation exercises, spatial reasoning tasks, and exposure to realistic terrain models. These sessions helped students build mental models of field environments, thus increasing their confidence and readiness before the actual fieldwork.

In the post-field phase, VR Svalbard VFE served as a reflective tool. Students revisited sites virtually to reinforce learning, compare virtual models with real-world observations, and identify aspects they may have missed in the field. This allowed for deeper engagement with the material and supported students' ability to connect observations across scales and contexts.

4.3.1 Pre-field experiences and perceptions

Before field excursions, students reported that virtual previews supported orientation and preparedness. The statement "Visiting the field localities virtually beforehand made the excursion more interesting" received a mean score of 4.0. VFEs were perceived to improve students' geographic orientation (mean 4.1), while the realism of the virtual models was also acknowledged (mean 4.2).

Within an ELT framework, this preparatory phase aligns with Abstract Conceptualization, where learners develop preliminary mental models before engaging in physical field experiences. By previewing landscapes and geological features, students appeared to form anticipatory conceptual structures that could later be tested in situ.

Negative statements such as "The VFG was a waste of time" received low mean scores (1.5), indicating general agreement with the platform's relevance. However, modest scores for statements reflecting boredom or underwhelm suggest that engagement may vary depending on instructional framing and interactivity.

4.3.2 Post-field reflections and learning consolidation

After completing field activities, students reflected on revisiting sites virtually. The statement "Re-visiting field localities virtually had a positive impact on my field learning" received a mean score of 3.9. Students reported that comparing in situ observations with high-resolution virtual imagery supported clarification and reinforcement of geological features.

This phase corresponds to Reflective Observation within ELT, as students revisited prior experiences, reinterpreted observations, and consolidated understanding. Rather than introducing new experiences, the VFEs functioned as a reflective scaffold, extending the experiential cycle beyond the temporal limits of fieldwork.

Students also reported feeling better prepared overall (mean 4.1), suggesting that post-field revisiting contributed to perceived consolidation of understanding.

4.3.3 Comparative insights: before vs. after fieldwork

Comparing pre- and post-field responses indicates that students perceived increased value in VFEs following physical field experience. While initial use supported orientation and anticipation, post-field revisiting appeared to support reflection and clarification.

When interpreted through Experiential Learning Theory, these patterns suggest that VFEs scaffold multiple stages of the learning cycle. Pre-field exposure supports Abstract Conceptualization. Physical fieldwork provides the Concrete Experience stage. Post-field revisiting aligns with Reflective Observation. Independent or extended use reflects Active Experimentation. Rather than replacing fieldwork, VFEs appear to redistribute and extend experiential processes across time and space.

Students were less supportive of replacing fieldwork entirely (mean 3.0 for partial replacement), reinforcing the complementary rather than substitutive role of digital tools.

4.3.4 Enhancing spatial awareness and geographical orientation

Spatial reasoning is central to geoscience fieldwork. A total of 83% of students agreed or fully agreed that VFEs improved their geographic orientation, and 85% positively evaluated the multi-scale integration of GIS maps and aerial imagery. Students reported that the layered visualizations helped them understand spatial context more effectively (Figure 7). These findings suggest that VFEs were perceived as supporting spatial orientation, particularly in complex Arctic landscapes.

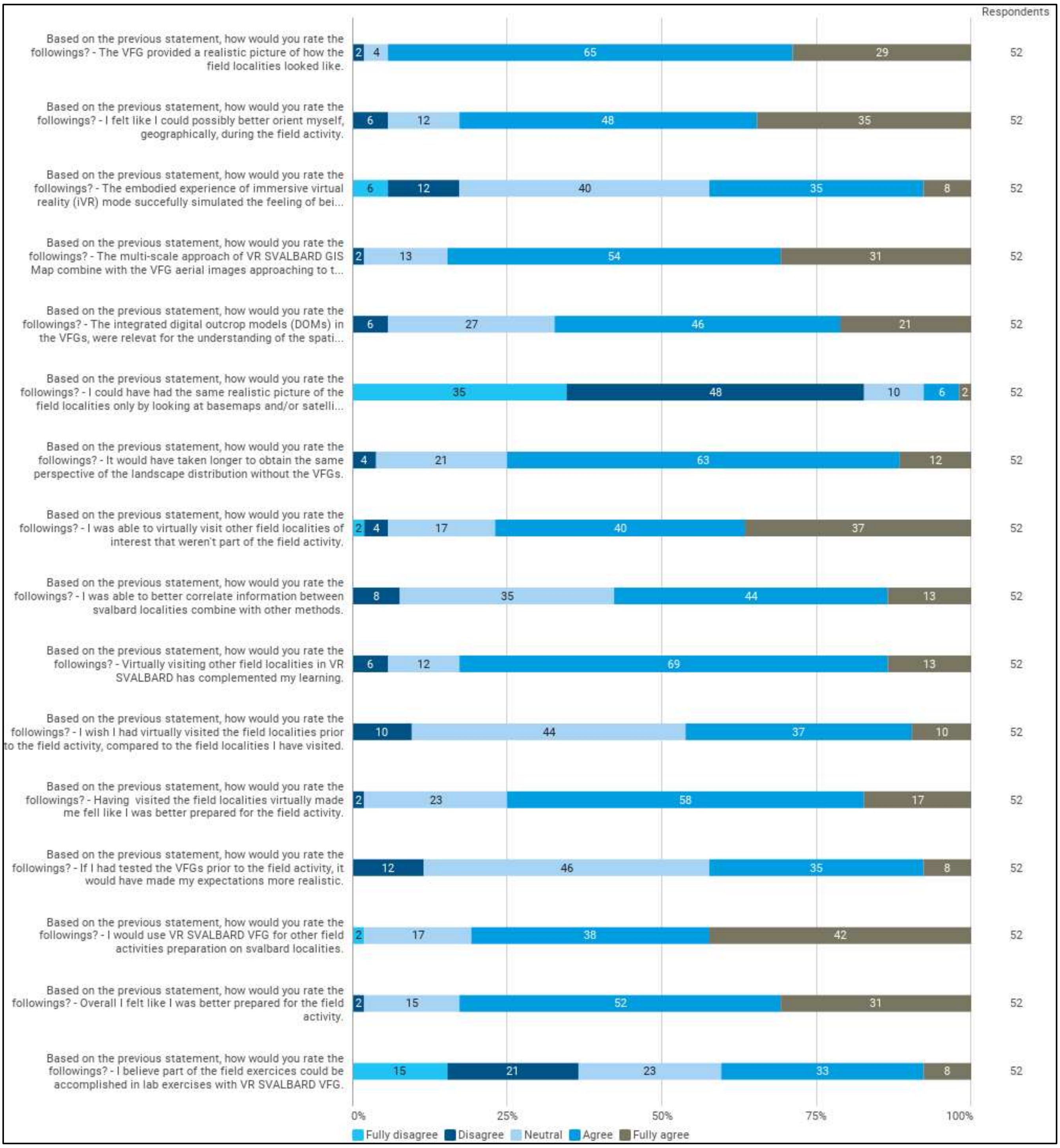


Figure 7: Full distribution of student responses to VFE-related statements, rated on a 5-point Likert scale (1 = fully disagree, 5 = fully agree). The chart visualizes levels of perception across key dimensions including spatial awareness, immersion, and learning outcomes.

4.3.5 Realism and immersion in virtual environments

Students generally found VFEs realistic but moderately immersive. Half of respondents agreed that immersive virtual reality simulated aspects of field presence, while a minority disagreed.

In contrast, 83% disagreed with the statement that satellite imagery alone would provide the same realism. Students therefore perceived added value in dynamic and interactive digital representations compared to static imagery.

These responses suggest that while VFEs were perceived as realistic, there remains scope for enhancing interactivity and immersive design.

4.3.6 Learning outcomes and preparation

Students reported that virtual visits contributed to perceived preparedness for field activities (75% positive responses). Additionally, 82% indicated that virtually visiting additional field localities complemented their learning.

Within the framework of novelty space, these perceptions suggest that VFEs may have reduced elements of environmental unfamiliarity by providing structured exposure prior to physical engagement. While the survey did not directly measure cognitive load or inclusion, reported increases in preparedness and orientation indicate that VFEs may help redistribute attention toward disciplinary observation rather than environmental adjustment.

Such redistribution may have implications for students with varying levels of prior field experience. However, further research would be required to examine these potential accessibility effects explicitly.

4.4 Suggestions for improvement and broader use cases

Open-ended responses highlighted areas for improvement, including navigation refinements, faster loading speeds, and additional guided exercises. Students also expressed interest in expanded use across courses, with 84% indicating willingness to use VR Svalbard for future field preparation.

Selected student comments illustrate both strengths and limitations:

> "Seeing the site in summer helped me understand what was under the snow."

> "We only saw 10% of the outcrop in spring—VR Svalbard showed the rest."

> "It would be nice to have more interactive exercises and guided tours."

These comments reflect perceived value in extending visibility, scale, and temporal access to field localities, while also indicating opportunities for further pedagogical refinement.

4.5 Practical experiences and costs

Developing the VFEs at UNIS was a gradual process that builds on incremental improvements and systematic data acquisition. We have been acquiring digital outcrop models at UNIS since 2017 and openly sharing them through the Svalbox portal (Betlem et al., 2023). We started acquiring aerial photospheres and building the VRSvalbard platform in 2021 (Horota et al., 2024). The online platforms themselves are affordable (approximately 10 000 EUR in total for development and ca 1 000 EUR per year for maintenance costs – web hosting largely) and sustainable for long-term maintenance. Data acquisition, however, is costly. A usual single field day in the high Arctic can easily cost 1 000 EUR covering transport in open boats or snowmobiles. UAVs used at UNIS (mostly DJI Mavic 2 Pro and Mavic 3) have exponentially improved in quality over the past decade and have modest costs (ca. 2000 EUR per UAV including controller). Education at UNIS is fully financed by the Norwegian Ministry of Education and Research. On average, educating one student-year (i.e. 60 ECTS) at UNIS costs ca. 10 000 EUR. In practice, this means that the courses studied by us (Table 2; typically 10-15 ECTS courses for up to 20 students) operate on total budgets of about 30 000 to 50 000 EUR including all field costs and travel/salary for guest lecturers, but excluding salary for UNIS-based course responsible staff. Field costs vary greatly between courses depending on the access to field site (walking, boating or snowmobiling), whether courses include overnight stay (cabins or hotel ships) and length of field work. With such high costs it is imperative that digital data (photospheres and digital outcrop models) are acquired opportunistically during courses or as part of research-based fieldwork.

In summary, running VFEs in general requires moderate resources and should be easily adoptable at most geoscience institutions. At UNIS, where the field access costs are significantly higher, VFEs are a must.

5 Discussion

This study examined how geoscience students engage with and perceive digital field representations integrated into Arctic field-based education. The findings indicate strong technological acceptance, perceived pedagogical value, and perceived support for preparedness and reflection. Rather than functioning as substitutes for physical fieldwork, VFEs were positioned by students as complementary tools that extend and scaffold experiential learning processes.

5.1 Technology acceptance as a prerequisite for pedagogical integration

Before evaluating pedagogical impact, it was necessary to establish whether the platform itself was accepted as usable and relevant. High scores across Perceived Usefulness, Perceived Ease of Use, and Behavioral Intention indicate that students viewed VR Svalbard as intuitive and educationally meaningful. This finding is important because technological friction can undermine learning outcomes (Davis, 1989; Venkatesh & Bala, 2008). If cognitive resources are diverted toward navigating an interface, they cannot be fully allocated to disciplinary reasoning. The strong acceptance observed here suggests that students' reported gains in preparedness and reflection were not confounded by usability barriers. Moreover, these results challenge assumptions that students are inherently comfortable with educational technology. Acceptance must be empirically demonstrated rather than presumed. In this case, technological usability appears to have enabled rather than obstructed experiential learning processes.

5.2 VFEs as scaffolds within experiential learning cycles

Interpreted through Experiential Learning Theory (Kolb, 1984), the findings suggest that VFEs supported multiple stages of the learning cycle. Pre-field engagement appeared to support Abstract Conceptualization by enabling students to construct preliminary mental models before entering the field. Students reported improved geographic orientation and familiarity, indicating that virtual previews contributed to anticipatory structuring of knowledge. Physical fieldwork then provided Concrete Experience, where sensory, spatial, and environmental dimensions of learning unfolded in situ. Post-field revisiting aligned with Reflective Observation. Students reported that returning to digital representations helped consolidate understanding and reinterpret previously observed features. In this way, VFEs extended reflection beyond the temporal constraints of field excursions. Independent exploration and optional engagement outside scheduled activities may reflect Active Experimentation, where learners test interpretations and navigate field sites in self-directed ways. Rather than compressing experiential learning into a limited field window, VFEs redistributed it across time and contexts. This temporal extension may be particularly valuable in environments where logistical constraints restrict repeated site visits.

5.3 Managing novelty space without eliminating experiential richness

Field-based education inherently involves novelty. In remote Arctic environments, students must process unfamiliar terrain, safety procedures, weather conditions, and spatial complexity simultaneously. Novelty space describes the cognitive and affective load associated with these first encounters (Stainfield et al., 2000). Students in this study reported increased preparedness and orientation following virtual previews. While the study did not directly measure cognitive load, the consistent pattern of improved familiarity suggests that VFEs may moderate environmental novelty prior to physical exposure. Importantly, managing novelty does not imply eliminating it. Some degree of unfamiliarity is pedagogically valuable and contributes to disciplinary identity formation. However, reducing excessive environmental disorientation may allow students to allocate greater cognitive resources toward geological interpretation rather than situational adjustment. In this sense, VFEs may calibrate novelty space rather than remove it.

5.4 Complementarity rather than substitution

Students did not strongly support replacing physical fieldwork with virtual alternatives. This reinforces existing studies emphasizing that VFEs are most effective when integrated alongside, rather than instead of, field experiences (Cliffe, 2017; Pugsley et al., 2021).

The findings suggest that students perceive digital field representations as:

- Tools for preparation
- Instruments for reflection
- Resources for revisiting inaccessible features
- Extensions of spatial visualization

This complementary framing avoids the false dichotomy of "virtual versus real" and instead positions VFEs as augmentative pedagogical infrastructure.

5.5 Implications for inclusivity and sustainability

The accessibility implications of VFEs may also extend beyond physical access to field sites. For some students, including neurodivergent students or those with limited prior field experience, unfamiliar field environments, social situations, safety procedures, and logistical uncertainty may increase anxiety and cognitive load before field activities begin. In this sense, VFEs may function partly like preparatory "social stories" (Gray and Garand, 1993), allowing students to preview what a field site, route, or activity may involve before encountering it in person. However, virtual environments may also constitute a novelty space in themselves, particularly for students with limited exposure to digital or immersive tools. Given that 42% of users engaged with VR Svalbard for less than one hour, future research should examine how technological novelty interacts with field novelty and how both influence learning outcomes.

In addition, VFEs provide access to localities that may be seasonally restricted, weather-limited, or logistically inaccessible. In the context of environmental sustainability and increasing scrutiny of travel-related carbon footprints, digital extensions of field learning may also offer opportunities to balance experiential depth with ecological responsibility.

5.6 Limitations and future research

Several limitations should be acknowledged. First, the study relies on self-reported perceptions rather than direct measurement of learning gains. While perceived preparedness and orientation are important indicators, future research should examine measurable impacts on spatial reasoning and field performance. Second, the study was conducted within a single institutional context in the High Arctic. The extent to which findings generalize to other geoscience settings requires further investigation. Third, novelty space was inferred from preparedness and orientation measures rather than directly operationalized through cognitive load instruments. Future studies could incorporate validated scales to assess cognitive and affective novelty more explicitly. Future research should also explore co-design approaches involving students and instructors to refine interactivity, task guidance, and integration strategies within VFEs.

6 Conclusions

In this study we have shown that VFEs, as delivered through the VR Svalbard platform, hold substantial potential for enhancing field-based geoscience education. Students at UNIS reported that these tools supported their learning by improving field preparedness, spatial awareness, and post-field reflection. By offering access to high-resolution, interactive, and scalable representations of Arctic field sites, VFEs address key challenges in accessibility, inclusivity, and sustainability in field teaching.

Importantly, student feedback indicates that the pedagogical value of VFEs lies not in replacing fieldwork but in complementing it, offering repeated, low-barrier opportunities to engage with field content across time and space. This affirms the potential of VFEs to scaffold learning in ways that align with experiential, iterative, and reflective educational approaches. Beyond technical adoption, the integration of VFEs also holds cultural and structural significance for the geoscience education community. These tools challenge traditional assumptions about what counts as 'real' field learning by enabling more varied and inclusive modes of engagement. Students' perspectives suggest that digital tools, when thoughtfully integrated, can democratize access to field sites, support learner agency, and reduce barriers related to physical ability, scheduling, and prior experience.

This broader integration of VFEs as complementary, inclusive, and learner-informed components of field education calls for continued dialogue between educators and students. As students may recognize the value of these digital tools before their instructors do, future research should explore how learners themselves contribute to shaping pedagogical innovation in geoscience. We recommend further inquiry into the co-construction of field learning environments, where student reflections, preferences, and feedback actively inform the evolution of field education practices.

A further consequence of integrating VFEs into field curricula is their potential to reduce the novelty space students experience when entering unfamiliar and demanding environments such as the High Arctic. In this study, students reported increased preparedness, spatial orientation, and opportunities for post-field reflection. While we did not directly measure improvements in quantitative geological field performance, these perceived benefits suggest that VFEs may help students enter field settings with greater familiarity and confidence, thereby supporting observation and interpretation during limited field time.

Data availability

The questionnaire instrument, anonymized survey dataset, response labels, aggregated summaries, and analysis tables supporting the figures, tables, and results presented in this manuscript are provided as Supplement S1. This supplementary spreadsheet includes the survey items, coded response labels, anonymized numerical responses, Likert-scale summaries, response counts, and descriptive statistics used in the analysis. No directly identifying information is included. Open-text responses have been reviewed and anonymized or excluded where necessary to comply with privacy, ethical, and GDPR-related restrictions associated with the consent under which the data were collected.

Author contributions

RKH conceived the study, developed the methodology, curated and analyzed the data, and wrote the original draft; CE, KS, MJ, and MAVK reviewed and edited the manuscript; KS and MJ also contributed to funding acquisition.

Competing interests

The authors declare that they have no conflict of interest.

Ethical statement

This study was conducted in accordance with ethical guidelines for research involving human participants. Ethical approval was obtained from the Norwegian Centre for Research Data (NSD, now Sikt – Norwegian Agency for Shared Services in Education and Research) under reference number 955880. All participants were informed about the objectives of the study and provided informed consent prior to data collection. Data were anonymized and handled in compliance with the General Data Protection Regulation (GDPR). The study adhered to institutional and national guidelines for responsible research practices.

Acknowledgements and funding

The authors would like to thank all the students who generously participated in the study and provided valuable insights. We are also grateful to the course coordinators at the University Centre in Svalbard (UNIS) for their support in integrating the research activities into their course structures. This research was made possible through funding from UNIS, which supported both the delivery of field-based courses and the PhD fellowship of the lead author (RKH). Additional support was provided by the iEarth Centre for Integrated Earth Science Education, which funded related pedagogical projects. The development and deployment of VR Svalbard and associated data acquisition were supported through the Svalbox and iEarth seed funding initiatives, which provided access to drones, digital equipment and field campaigns. Their combined support was instrumental in enabling this research at the intersection of digital innovation and Arctic geoscience education. Finally we sincerely thank the four journal reviewers Clare Bond, Rie Malm, Christopher Skinner and Valentin Zuchuat and the journal Editor Stephanie Zihms for their constructive feedback that greatly improved an original version of the manuscript.

Generative AI disclosure. ChatGPT with DALL·E was used only to generate the background illustrative images included in Figure 1. These images were generated separately, using author-provided reference material and stage-specific prompts. The prompts are the following:

1. “Create a clean academic background illustration representing geoscience students preparing for Arctic fieldwork using digital field tools and virtual field experiences. Use a professional scientific illustration style. Do not depict real identifiable people, real research data, or a specific field site.”

2. “Create a clean academic background illustration representing geoscience field observation in an Arctic landscape, with students examining geological features in the field. Use a professional scientific illustration style. Do not depict real identifiable people, real research data, or a specific field site.”
3. “Create a clean academic background illustration representing post-field reflection, with students or researchers reviewing digital field representations, maps, or virtual outcrop material after fieldwork. Use a professional scientific illustration style. Do not depict real identifiable people, real research data, or a specific field site.”
4. “Create a clean academic background illustration representing reinterpretation and active experimentation using virtual field environments, digital outcrop models, maps, and geoscience visualization tools. Use a professional scientific illustration style. Do not depict real identifiable people, real research data, or a specific field site.”

References

Betlem, P., Rodés, N., Birchall, T., Dahlin, A., Smyrak-Sikora, A., and Senger, K.: Svalbox Digital Model Database: A geoscientific window into the High Arctic, Geosphere, 19, 1640–1666, doi:10.1130/GES02606.1, 2023.

Bimba, A. T., Idris, N., Al-Hunaiyyan, A., Ibrahim, S. U., Mustafa, N., Supa’at, I., ... & Ahmad, M. Y. (2021). The effects of adaptive feedback on student’s learning gains. International Journal of Advanced Computer Science and Applications, 12(7), 68-80.

Bonali, F., Russo, E., Vitello, F., Antoniou, V., Marchese, F., Fallati, L., Bracchi, V., Corti, N., Savini, A., Whitworth, M., Drymoni, K., Mariotto, F., Nomikou, P., Sciacca, E., Bressan, S., Falsaperla, S., Reitano, D., Van Wyk De Vries, B., Krokos, M., … Tibaldi, A. (2021). How Academics and the Public Experienced Immersive Virtual Reality for Geo-Education. Geosciences, 12(1), 9. https://doi.org/10.3390/geosciences12010009

Bond, C.E. and Cawood, A.J., 2020. 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, pp.1-20.

Boyle, A., Maguire, S., Martin, A., Milsom, C., Nash, R., Rawlinson, S., Turner, A., Wurthmann, S., and Conchie, S.: Fieldwork is good: The student perception and the affective domain, Journal of Geography in Higher Education, 31, 299–317, doi:10.1080/03098260601063628, 2007.

Carabajal, I. G., Marshall, A. M., & Atchison, C. L. (2017). A Synthesis of Instructional Strategies in Geoscience Education Literature That Address Barriers to Inclusion for Students With Disabilities. Journal of Geoscience Education, 65(4), 531–541. https://doi.org/10.5408/16-211.1

Cliffe, A. D. (2017). 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), 1-14.

Davis, F.D., 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS quarterly, pp.319-340.

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

Evelpidou, N., Karkani, A., Saitis, G., and Spyrou, E.: Virtual field trips as a tool for indirect geomorphological experience: A case study from the southeastern part of the Gulf of Corinth, Greece, Geoscience Communication, 4, 351–360, doi:10.5194/gc-4-351-2021, 2021.

Feig, A. D., Atchison, C., Stokes, A., & Gilley, B. (2019). Achieving Inclusive Field-based Education: Results and Recommendations from an Accessible Geoscience Field Trip. Journal of the Scholarship of Teaching and Learning, 19(2). https://doi.org/10.14434/josotl.v19i1.23455

Giles, S., Jackson, C., & Stephen, N. (2020). Barriers to fieldwork in undergraduate geoscience degrees. Nature Reviews Earth & Environment, 1(2), 77-78. https://doi.org/10.1038/s43017-020-0022-5

Gray, C. A., and Garand, J. D.: Social stories: Improving responses of students with autism with accurate social information, Focus on Autistic Behavior, 8(1), 1–10, doi:10.1177/108835769300800101, 1993.

Guillaume, L., Laurent, V., & Genge, M. J. (2023). 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.

Hassan, M. A., Habiba, U., Khalid, H., Shoaib, M., & Arshad, S. (2019). An adaptive feedback system to improve student performance based on collaborative behavior. Ieee Access, 7, 107171-107178.

Hay, K. E., Marlino, M., & Holschuh, D. R. (2013, April). The virtual exploratorium: Foundational research and theory on the integration of 5-D modeling and visualization in undergraduate geoscience education. In International Conference of the Learning Sciences (pp. 214-220). Psychology Press.

Heimann, S., & Johansson, K. (2024). Gendered work in geoscience: Hard work in a masculine field. Gender, Work & Organization, 31(1), 16–35. https://doi.org/10.1111/gwao.13052

Horota, R.K., Rossa, P., Marques, A., Gonzaga, L., Senger, K., Cazarin, C.L., Spigolon, A. and Veronez, M.R., 2022. An immersive virtual field experience structuring method for geoscience education. IEEE Transactions on Learning Technologies, 16(1), pp.121-132.

Horota, R. K., Senger, K., Rodes, N., Betlem, P., Smyrak-Sikora, A., Jonassen, M. O., Kramer, D., and Braathen, A.: West Spitsbergen fold and thrust belt: A digital educational data package for teaching structural geology, *Journal of Structural Geology*, **167**, 104781, https://doi.org/10.1016/j.jsg.2022.104781, 2023.

Horota, R.K., Senger, K., Smyrak-Sikora, A., Furze, M., Retelle, M., Vander Kloet, M.A. and Jonassen, M.O., 2024. VRSvalbard–a Photosphere-Based Atlas of a High Arctic Geo-Landscape. First Break, 42(4), pp.35-42.

Howell, J. A., Martinius, A. W., and Good, T. R.: The application of outcrop analogues in geological modelling: A review, present status and future outlook, Geological Society, London, Special Publications, 387, 1–25, doi:10.1144/SP387.12, 2014.

Jakobsson, M., Macnab, R., Mayer, L. A., Anderson, R., Edwards, M., Hatzky, J., Schenke, H. W., and Johnson, P.: An improved bathymetric portrayal of the Arctic Ocean: Implications for ocean modeling and geological, geophysical and oceanographic analyses, Geophysical Research Letters, 35, L07602, doi:10.1029/2008GL033520, 2008.

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

Lonergan, N., & Andresen, L. W. (1988). Field-based education: Some theoretical considerations. Higher education research and development, 7(1), 63-77.

Malm, R. H. (2020). *What is fieldwork for? Exploring Roles of Fieldwork in Higher Education Earth Science* (Publication No. 2349) [Doctoral dissertation, University of Oslo]. http://hdl.handle.net/10852/82828.

Malm, R. H., Madsen, L. M., & Lundmark, A. M. (2020). Students' negotiations of belonging in geoscience: Experiences of faculty–student interactions when entering university. Journal of Geography in Higher Education, 44(4), 532–549. https://doi.org/10.1080/03098265.2020.1771683

Marín-Spiotta, E., Barnes, R. T., Berhe, A. A., Hastings, M. G., Mattheis, A., Schneider, B., & Williams, B. M. (2020). Hostile climates are barriers to diversifying geosciences. Advances in Geosciences, 53, 117–127. https://doi.org/10.5194/adgeo-53-117-2020

Mattheis, A., Marín-Spiotta, E., Nandihalli, S., Schneider, B., & Barnes, R. T. (2022). " Maybe this is just not the place for me:" Gender harassment and discrimination in the geosciences. PLoS One, 17(5), e0268562.

Mead, C., Buxner, S., Bruce, G., Taylor, W., Semken, S. and Anbar, A.D., 2019. Immersive, interactive virtual field trips promote science learning. Journal of Geoscience Education, 67(2), pp.131-142.

Metzger, E.P., 2024. Reimagining geoscience education for sustainability. Earth Science, Systems and Society, 4(1), p.10116.

Mol, L., & Atchison, C. (2019). Image is everything: Educator awareness of perceived barriers for students with physical disabilities in geoscience degree programs. Journal of Geography in Higher Education, 43(4), 544–567. https://doi.org/10.1080/03098265.2019.1660862

Moysey, S.M. and Lazar, K.B., 2019. Using virtual reality as a tool for field-based learning in the earth sciences. Interdisciplinary perspectives on virtual place-based learning, pp.99-126.

Núñez, A. M., Posselt, J. R., Hallmark, T., Rivera, J., & Southern, D. (2021). The organization of learning in geoscience fieldwork and implications for inclusion. Journal of Women and Minorities in Science and Engineering, 27(3).

Olaussen, S., Grundvåg, S.A., Senger, K., Anell, I., Betlem, P., Birchall, T., Braathen, A., Dallmann, W., Jochmann, M., Johannessen, E.P. and Lord, G., 2025. Svalbard composite tectono-sedimentary element, Barents Sea. Geological Society, London, Memoirs, 57(1), pp.M57-2021.

Posselt, J. R., & Nuñez, A.-M. (2022). Learning in the Wild: Fieldwork, Gender, and the Social Construction of Disciplinary Culture. The Journal of Higher Education, 93(2), 163–194. https://doi.org/10.1080/00221546.2021.1971505

Pugsley, J. H., Howell, J. A., Hartley, A., Buckley, S. J., Brackenridge, R., Schofield, N., ... & Vanbiervliet, J. (2021). Virtual Fieldtrips: construction, delivery, and implications for future geological fieldtrips. Geoscience Communication Discussions, 2021, 1-33.

Pugsley, J., Howell, J., Hartley, A., Buckley, S. J., Chmielewska, M., Naumann, N., ... & Brackenridge, R. (2024). Quantifying Virtual Field Trip Efficiency. PFG–Journal of Photogrammetry, Remote Sensing and Geoinformation Science.

Senger, K., Betlem, P., Grundvåg, S. A., Horota, R. K., Buckley, S. J., Smyrak-Sikora, A., ... & Olaussen, S. (2021). Teaching with digital geology in the high Arctic: opportunities and challenges. Geoscience Communication Discussions, 2021, 1-39.

Senger, K., Ammerlaan, F., Betlem, P., Dumais, M.-A., Eagles, G., Foster, W., Geissler, W. H., Grundvåg, S.-A., Hudson, A., Horota, R. K., Hurum, J. H., Jones, M., Kierulf, H. P., Majka, J., Marsden, L., Michalski, K., Minakov, A., Ogata, K., Olaussen, S., Osmundsen, P. T., Planke, S., Ruppel, A., Sartell, A. M. R., Shephard, G., Śliwińska, K. K., Smeraglia, L., Smyrak-Sikora, A., Spiegel-Behnke, C., and Zuchuat, V.: Geology of Svalbard: Deep-time and Deep-Earth (SVALGEOL), in: SESS Report 2024: The State of Environmental Science in Svalbard – an annual report, edited by Runge, E., Neuber, R., Łupikasza, E., Hübner, C., and Holmén, K., Svalbard Integrated Arctic Earth Observing System, Longyearbyen, doi:10.5281/zenodo.14425478, 2025.

Stainfield, J., Fisher, P., Ford, B. and Solem, M., 2000. International virtual field trips: A new direction?. Journal of Geography in Higher Education, 24(2), pp.255-262.

Stott, T., Litherland, K., Carmichael, P., & Nuttall, A. M. (2014). Using interactive virtual field guides and linked data in Geoscience teaching and learning. Geoscience Research and Education: Teaching at Universities, 163-188.

Stokes, A., Feig, A. D., Atchison, C. L., & Gilley, B. (2019). Making geoscience fieldwork inclusive and accessible for students with disabilities. Geosphere, 15(6), 1809–1825. https://doi.org/10.1130/GES02006.1

Stokes, P. J., Levine, R., & Flessa, K. W. (2015). Choosing the geoscience major: Important factors, race/ethnicity, and gender. Journal of Geoscience Education, 63(3), 250-263.

Suthren, R. J. (1998). Virtual posters and virtual essays in geoscience courses. Computers & Geosciences, 24(7), 665-671.

Venkatesh, V. and Bala, H., 2008. Technology acceptance model 3 and a research agenda on interventions. Decision sciences, 39(2), pp.273-315.

Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J. and Reynolds, J.M., 2012. 'Structure-from-Motion'photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology, 179, pp.300-314.

Whitmeyer, S., Atchison, C., & Collins, T. (2020). Using Mobile Technologies to Enhance Accessibility and Inclusion in Field-Based Learning. GSA Today, 30(9), 4–10. https://doi.org/10.1130/GSATG462A.1

Appendix A

Regarding the TECHNICAL aspects of VR SVALBARD, how would you rate the following statements?

	Extremely unlikely	Quite unlikely	Slightly unlikely	Neither	Slightly likely	Quite likely	Extremely likely
Using VR SVALBARD in my field studies would enable me to accomplish tasks more quickly.	1	2	3	4	5	6	7
Using VR SVALBARD in my field studies would increase my productivity.	1	2	3	4	5	6	7
Using VR SVALBARD would enhance my effectiveness in the field.	1	2	3	4	5	6	7
Using VR SVALBARD would improve my field learning performance.	1	2	3	4	5	6	7
Using VR SVALBARD would make field related tasks easier.	1	2	3	4	5	6	7
I would find VR SVALBARD useful in my field learning activity.	1	2	3	4	5	6	7
Learning to operate VR SVALBARD would be easy for me.	1	2	3	4	5	6	7
I would find it easy to get VR SVALBARD to do what I want it to do.	1	2	3	4	5	6	7
My interaction with VR SVALBARD would be clear and understandable.	1	2	3	4	5	6	7
I would find VR SVALBARD to be flexible to interact with	1	2	3	4	5	6	7
It would be easy for me to become skillful at using VRSVALBARD	1	2	3	4	5	6	7
I would find VR SVALBARD easy to use.	1	2	3	4	5	6	7
I intend to use VR Svalbard frequently in the future.	1	2	3	4	5	6	7
I will recommend VR Svalbard to others.	1	2	3	4	5	6	7
I plan to integrate VR Svalbard into my academic activities.	1	2	3	4	5	6	7
I would consider using other VR Systems based on my experience with VR Svalbard.	1	2	3	4	5	6	7

Figure A1. Technology Acceptance Model (TAM) questionnaire items used to assess students' perceptions of the technical aspects of VR Svalbard. The instrument included items related to perceived usefulness, perceived ease of use, and behavioural intention to use the platform. Responses were recorded on a 7-point Likert scale ranging from 1 = extremely unlikely to 7 = extremely likely.

Appendix B

Based on your VR SVALBARD VFG experience BEFORE going to the field activity, how would you rate the following statements?

	Fully disagree	Disagree	Neutral	Agree	Fully agree
I was bored.	○	○	○	○	○
The VFG felt like a complete waste of time.	○	○	○	○	○
Visiting the field localities virtually beforehand made the excursion more interesting.	○	○	○	○	○
Visiting the field localities virtually beforehand had great impact on my final learning outcome.	○	○	○	○	○
I think visiting the field localities virtually prior to the excursion was not worth the time invested.	○	○	○	○	○

Based on your VR SVALBARD experience AFTER going to the field activity, how would you rate the following statements?

	Fully disagree	Disagree	Neutra	Agree	Fully agree
I was bored	○	○	○	○	○
The VFG felt like a complete waste of time.	○	○	○	○	○
I think visiting the field localities virtually beforehand would have little impact on my final learning outcome.	○	○	○	○	○
I think some of the field exercises could have been done in the preparation lecture using the VFGs.*	○	○	○	○	○
I wish I had more time in the field preparation lecture with VFGs to better prepare for the field excursion.	○	○	○	○	○
Re-visiting field localities virtually had little impact for course activity purposes.	○	○	○	○	○
Re-visiting field localities virtually had a positive impact on my field learning outcomes.	○	○	○	○	○

*What field exercises could have been done virtually?

	Fully disagree	Disagree	Neutral	Agree	Fully agree
The VFG provided a realistic picture of how the field localities looked like.	○	○	○	○	○
I felt like I could possibly better orient myself, geographically, during the field activity.	○	○	○	○	○
The embodied experience of immersive virtual reality (iVR) mode succefully simulated the feeling of being present at the field localities.	○	○	○	○	○
The multi-scale approach of VR SVALBARD GIS Map combine with the VFG aerial images approaching to the field localities, helped me better understand the scale and distribution of landscape.	○	○	○	○	○
The integrated digital outcrop models (DOMs) in the VFGs, were relevat for the understanding of the spatial distribution (3D), and scale of the landscape in field localities.	○	○	○	○	○
I could have had the same realistic picture of the field localities only by looking at basemaps and/or satellite imagery.	○	○	○	○	○
It would have taken longer to obtain the same perspective of the landscape distribution without the VFGs.	○	○	○	○	○
I was able to virtually visit other field localities of interest that weren't part of the field activity.	○	○	○	○	○
I was able to better correlate information between svalbard localities combine with other methods.	○	○	○	○	○
Virtually visiting other field localities in VR SVALBARD has complemented my learning.	○	○	○	○	○
I wish I had virtually visited the field localities prior to the field activity, compared to the field localities I have visited.	○	○	○	○	○
Having visited the field localities virtually made me fell like I was better prepared for the field activity.	○	○	○	○	○
If I had tested the VFGs prior to the field activity, it would have made my expectations more realistic.	○	○	○	○	○
I would use VR SVALBARD VFG for other field activities preparation on svalbard localities.	○	○	○	○	○
Overall I felt like I was better prepared for the field activity.	○	○	○	○	○
I believe part of the field exercices could be accomplished in lab exercises with VR SVALBARD VFG.	○	○	○	○	○

Figure B1. Educational impact questionnaire items used to assess students’ perceptions of VR Svalbard Virtual Field Guides before and after physical field activities. The pre-field section evaluated students’ expectations, engagement, and perceived value of visiting field localities virtually before fieldwork. The post-field section evaluated perceived learning impact, realism, immersion, spatial understanding, preparedness, and the perceived potential for using Virtual Field Guides in field preparation and laboratory-based activities. Responses were recorded on a 5-point Likert scale ranging from 1 = fully disagree to 5 = fully agree. Open-text fields were included to allow students to elaborate on which field exercises could have been done virtually