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Science communication in unexpected places

PRACTICE INSIGHTS

Glaciers as classrooms: designing an outdoor lab as a learning space on ice

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Abstract

This article presents the development of a hybrid educational format that integrates an outdoor glacier laboratory with a virtual learning environment. Grounded in Educational Design Research, the project enables students to investigate glacial and climate-related phenomena through hands-on experiments conducted directly on the glacier, complemented by immersive digital tools. Insights from pilot implementations with school classes informed iterative refinement. The approach illustrates how glacier environments can be transformed into accessible and pedagogically coherent learning spaces, promoting climate literacy and student engagement with real-world environmental change.

Keywords

Science education; Environmental communication; Bridging research; practice and teaching

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1 ▪ Introduction

Glacier retreat and the transformation of alpine and arctic regions have recently gained significant media and public attention. These massive changes are frequently mentioned as compelling evidence of climate change, underscoring their ecological and societal significance [Intergovernmental Panel on Climate Change (IPCC), 2014]. Despite glaciers serving as a striking example of climate change, many learners exhibit only limited knowledge about glaciers [Felzmann, 2017].

Although these environments possess both ecological and societal relevance, they remain physically distant and abstract for most learners. From the perspective of science education, glaciers offer a diverse field of phenomena for exploration both in classrooms and in the field. They are not only related to climate change but also to understand basic scientific phenomena such as properties of water in its different phases as well as landscaping processes in general [Felzmann, 2017]. However, most students encounter glaciers only through textbook images or isolated curricular references. Existing initiatives that offer virtual glacier experiences often emphasize geographical or visual aspects, while neglecting opportunities for experimentation and deeper disciplinary engagement [Gielstra et al., 2024; Kelly et al., 2024].

To address this desideratum, a project was initiated to develop integrated learning environments that enable students to investigate glacier-related phenomena across multiple contexts: in the field and in the classroom, supported by digital media. The approach is grounded in the principles of place-based education [Sobel, 2005]. Research suggests that direct experience with climate-affected landscapes can foster ecological awareness and strengthen personal engagement with global environmental issues [Young et al., 2020]. From the outset, the idea of creating an outdoor laboratory on a glacier formed a central vision of the project "GlacierXperience". This vision became operational through a collaboration with the Dachstein cable car company in Austria, who provided access to a glacier environment suitable for school visits. In parallel, a digital learning environment and classroom-based experiments were developed to ensure that all students could engage with the same core scientific content. The conceptual development of all learning spaces proceeded simultaneously, ensuring consistency and flexibility across physical and virtual formats.

The project "GlacierXperience" was carried out through a transnational collaboration between the University of Graz in Austria (chemistry education and science communication), the University of Siegen in Germany (chemistry- and geography education), and UiT — The Arctic University of Norway (science education). The target group consisted of upper secondary school students aged 16–18, who engaged with the project both in classroom-based sessions and during field visits. Pilot implementations were conducted on glaciers in Austria and Norway as well as in partner schools in Austria and Germany, ensuring that the learning environments were tested in both outdoor and formal classroom contexts.

This article outlines the design process and educational rationale behind these learning environments, with particular focus on the outdoor glacier lab. It details the identification of scientific phenomena suitable for exploration, the iterative development and testing of experiments, and the integration of student feedback.

2 ▪ Theoretical framework

The design of glacier-related learning environments is grounded in a range of educational theories and pedagogical models. These frameworks inform the development of content, the formulation of learning objectives, and the design of the learning environments.

A key issue of this project is the concept of climate literacy, understood as knowledge of fundamental climate principles, recognition of human impacts, and the capacity for climate-informed decision-making. In our project, this includes understanding glacial dynamics, their link to climate change, and the societal implications of glacial retreat. Recent work emphasizes that climate literacy extends beyond factual knowledge to include critical engagement with scientific information and its societal context [Stadler et al., 2024; Wildbichler et al., 2025]. Reviews show that while students grasp basic ideas such as global warming, they often struggle with complex aspects like climate systems or the carbon cycle, which poses challenges for designing effective interventions [Wildbichler et al., 2025]. This supports broader arguments that fostering climate literacy requires not only conceptual understanding but also the ability to apply knowledge in decision-making contexts [Bhattacharya et al., 2021].

A central principle in science education is the recognition that learners bring prior knowledge and preconceptions into the classroom. These are shaped by everyday experiences, cultural narratives, and media exposure into the classroom. Felzmann [2017] identified common misconceptions related to glaciers, including the conflation of glaciers with icebergs and misunderstandings about glacial dynamics. However, there is a lack of broader empirical data on students' conceptions of glaciers. To address this gap, the project included the collection and analysis of students' prior knowledge and questions. These insights informed both the selection of scientific phenomena and the design of learning activities. To engage students with these phenomena, it is not only essential to consider *what* they already know, but also *where* and *how* they learn. This is where the concept of place-based education becomes especially relevant. Place-based education emphasizes learning that is grounded in local, meaningful, and ecologically relevant settings [Smith, 2002; Sobel, 2005]. Glaciers as physical locations offer a rich context for interdisciplinary learning and personal engagement. Field-based learning experiences can help students to connect abstract scientific content with real-world phenomena [Young et al., 2020]. This approach aligns with contemporary science communication, which emphasizes engagement through meaningful, contextual experiences rather than mere knowledge transfer [Davies & Horst, 2016]. While the classical definition highlights accessibility and understanding [Burns et al., 2003]. Recent perspectives stress dialogic and participatory dimensions. In educational contexts, this means fostering scientific citizenship and enabling learners to critically engage with scientific information. Integrating place-based education with science communication thus creates opportunities for both conceptual understanding and communicative competency in climate science, in line with collaborative design approaches that involve scientists, practitioners, and audiences in co-creating communication formats [Enzingmüller & Marzavan, 2024].

Previous work has shown that outdoor science labs and field-based education offer distinctive affordances for learning compared to traditional classroom settings. Such environments influence not only cognitive but also affective outcomes, such as motivation and environmental awareness, and their potential in science education is well documented [Dillon et al., 2006; Höper & Köller, 2018; Orion, 2019; Orion & Hofstein, 1994]. The

“GlacierXperience”-project builds on this tradition but is distinctive in situating learning in a glacial environment while combining outdoor immersion with digital augmentation and participatory design.

The development of the glacier lab was guided by Educational Design Research (EDR) [McKenney & Reeves, 2019], an approach that integrates iterative design with systematic inquiry in authentic educational contexts such as outdoor and blended learning. Closely related to Design-Based Research (DBR) [The Design-Based Research Collective, 2003], EDR emphasizes practical solutions, collaboration with practitioners, and the generation of usable educational products while still contributing to theory. In this project, we adopt the EDR terminology to highlight the practical orientation of our work and its integration of design, implementation, and evaluation within real school contexts. The three EDR phases that are analysis and exploration, design and construction, and evaluation and reflection, are embedded in a reflective cycle to produce both context-specific and generalizable knowledge.

3 ▪ Rationale and aims

To address the knowledge gap and enhance scientific literacy among students across Europe, a project was initiated to bring alpine and polar science into the classroom. In a transnational collaboration between the University of Graz (Austria), The Arctic University of Norway, UiT (Tromsø), and the University of Siegen (Germany), indoor and outdoor student labs on the topic of glaciers were developed. A multifaceted design was chosen, combining model-based experimentation with an immersive 360° learning environment. Virtual Reality was integrated to create a virtual glacier experience accessible to all students. The project pursued the following aims:

1. Identify scientific phenomena related to glaciers, ice and alpine regions.
2. Transform current Alpine and Arctic research into experiments and student learning opportunities.
3. Investigate students’ prior knowledge and questions related to glaciers in Alpine and Arctic regions.
4. Design a classroom-based student laboratory that integrates scientific, geographic, and environmental perspectives and experiments on glaciers and offers a virtual glacier experience.
5. Develop an outdoor laboratory where scientific phenomena on the glacier can be discovered and experienced on an easily accessible glacier.

4 ▪ Methods

The development process of the learning environment followed the Educational Design Research approach as described by McKenney and Reeves [2019]. This model emphasizes iterative cycles of analysis, design, evaluation, and revision in authentic educational settings (see Figure 1). The project progressed through several development phases, including the identification of relevant scientific phenomena through literature review and expert

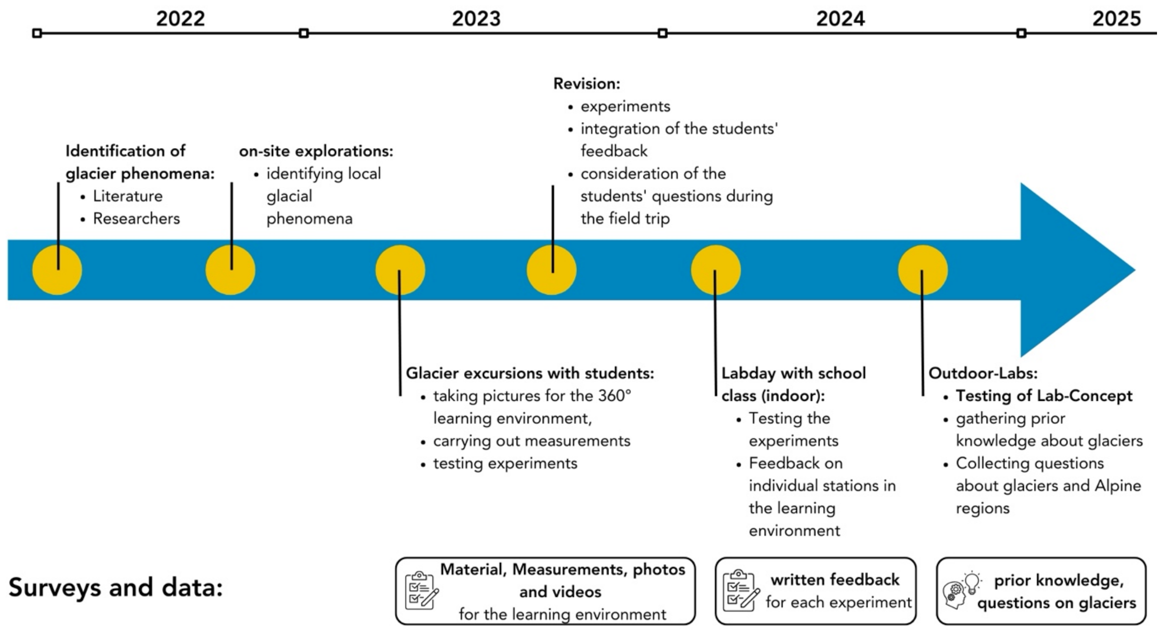

Figure 1. Overview of the project's development process.

consultation, the design of indoor and outdoor experiments as well as immersive digital tools, and the evaluation and refinement of materials through multiple rounds of school-based implementation. Each phase informed the next, and the design evolved through continuous feedback from both students and teachers. A set of design principles and associated design criteria was defined for the project (see Table 1).

To determine which scientific phenomena could be meaningfully explored in the context of glaciers, the project team conducted a multi-pronged research process. This included a review of recent scientific literature on alpine and polar regions, covering topics such as acid mining [Thies et al., 2013] and heavy metals in glacial lakes [Hawkings et al., 2021]. Formal and informal consultations and exchanges were conducted with glaciologists, including the research group around glaciologist Jemma Wadham from the Arctic University. In total, eight scientists were consulted. Four of them were glaciologists involved in the Metallica project, focusing on trace metals and biogeochemical processes in glacier systems. Discussions with this group addressed glacial phenomena suitable for educational exploration, fieldwork-techniques and processes of glacial meltwater chemistry. Additional input was provided by a geomorphologist from the University of Vienna, who advised on geomorphological processes, acid mine drainage, and the occurrence of heavy metals in alpine meltwater. Two physical chemists from the University of Graz supported the analysis of mineral samples using X-ray reflectometry. Finally, an outdoor education specialist from the Arctic University advised on the pedagogical design and safety considerations of field-based learning. These interdisciplinary consultations complemented the literature review and ensured that the selected glacial phenomena and experiments were both scientifically accurate and pedagogically feasible.

Additionally, field visits were carried out to two glacier sites: the Hallstätter Glacier at the Dachstein massif in Austria and the Steindalsbreen Glacier in Norway. During these

Table 1. Design principles and design criteria.

Design Principle	Design Criteria
Authenticity and relevance	• Learning content is grounded in real-world phenomena from glacier environments. • Experiments and activities are informed by current research in Alpine and Arctic regions.
Multimodality and immersion	• The experiments will be made available on a digital learning platform that also enables a glacier experience with the help of 360° images. • Experiments are available in both physical and virtual formats.
Student-centred participation	• Content development is guided by students' prior knowledge and questions. • Student feedback is systematically used to refine experiments and instructions.
Accessibility and adaptability	• Materials are usable both on-site (glacier) and in classrooms.
Interdisciplinary integration	• Content integrates concepts from geography, biology, chemistry, and physics. • Materials are co-developed with experts from multiple academic disciplines.
Inquiry-based and reflective learning	• Experiments follow fundamental scientific procedures, such as observation, measurement, and analysis. • Learning activities encourage reflection on scientific processes and outcomes.

excursions, the team observed local conditions, documented landscape features, and gathered ideas for student experiments. As part of an early test phase, the team conducted a two-day glacier excursion with a group of 10 secondary school students aged 16–17 years at the Hallstätter Glacier (see Figure 2). These students have taken an elective course on regional mountain geography at their school. At the Hallstätter Glacier, initial field measurements were taken, and 360° photos and videos were captured to form the basis of the digital learning environment. While no systematic data were collected at this stage, observational notes and subjective impressions of student engagement were used to guide further development. The identified phenomena were categorized into thematic clusters, including glacier dynamics and movement, meltwater chemistry, albedo effects, cryoconite analysis, plant adaptation in alpine environments, and physical effects of altitude on the human body.

To gain insights into students' prior knowledge and their questions related to glaciers, a structured feedback tool was employed during both the indoor and outdoor lab phases. Six school classes participated in total, comprising 83 students aged 16–18 from middle and upper secondary schools in Austria and Germany (three Austrian school groups (n=44) and three German school groups (n=39)). All participating students had basic background knowledge in geography and natural sciences but no specialized training in glaciology or climate science. At the beginning of the sessions, students were given color-coded cards. On one set of cards, they were asked to write down what they already knew about glaciers; on the other, they noted any questions they had on the topic. The responses were transcribed, clustered and analysed using qualitative content analysis [Kuckartz, 2014].

Figure 2. Students during excursion on the Hallstätter glacier.

The findings from the literature review, fieldwork, and student engagement are presented in the following thematic sections, including selected glacial phenomena, student conceptions, and evaluation results from classroom and field testing.

5 ▪ From scientific phenomena to learning opportunities

The movement of glacial ice has a significant impact on the landscape, shaping the environment as it advances and retreats. Black deposits (cryoconite) that cover the glacier ice and are visible especially in summer, exemplify issues exacerbated by climate change [Vincent & Laybourn-Parry, 2008]. These phenomena also include biological adaptations to harsh conditions, such as *Saxifraga paniculata*, found in karst stone environments surrounding some of the glaciers, which releases calcium carbonate through its leaves as a protective mechanism [Michavila et al., 2022]. The melting of glaciers and permafrost can also trigger a range of downstream effects, such as acidification or the release of heavy metals into aquatic systems [Jones et al., 2019]. Current research also discusses, there have been discussions regarding the role of glaciers and ice sheets in the global carbon cycle [Hood et al., 2015; St. Pierre et al., 2019; Wadham et al., 2019].

A thematic analysis of scientific literature, expert consultation, and field observations led to the identification of key scientific phenomena relevant to glacial and alpine environments.

These were organized into six thematic clusters, which formed the basis for the student lab design (see Table 2). For each theme, corresponding experiments were developed. Based on

Table 2. Key phenomena.

General Topic	**Phenomena**	**Experiment/Content**
Understanding the glacier	Glacier Movement	Model experiment on crevasse formation using kinetic sand
	Glacier Ice	Observation of ice layers during a visit to the “Ice Palace”
	Shaping of the landscape by the glacier	
	Analysis of glacier water	Measuring conductivity of snow, glacier water, and tap water
Glacier landscapes	Adaptations of alpine plants	Investigation of *Saxifraga paniculata* and its calcareous glands
	Karst landscape on Dachstein	Water absorption in karst (limestone) terrain
	Colour variations in rocks	Simple ion detection to analyse rock colour differences
Alpine phenomena	Dark surface layers on ice	Collection and analysis of cryoconite
		Albedo measurements using a light meter
	Edge gap to the Dachstein	Thermal imaging of surface temperature variations
		Measuring the albedo with the light meter
Phenomena that affect me on the mountain	Boiling point at altitude	Comparing the boiling point of water at the glacier and in the valley
	Pressure changes in a cable car	Measuring air pressure changes with a smartphone
		PET bottle experiment demonstrating pressure variation during descent
Alpine and Polar Research	Acid mine drainage	
	Heavy metal contamination in meltwater	
Future Lab	Carbon Capture and Storage (CCS)	Glaciers as CO_2-Sink
		CCS through chemical weathering processes

the identified themes, initial versions of the experiments were developed. To test their feasibility, clarity, and potential for student engagement, a combined field-course and classroom teaching unit in Norway [Sørensen, 2024] and a laboratory day in Austria were organized in early 2024, each involving one school class. At this stage, the experiment instructions and parts of the digital learning environment were already available. Each experiment station included a feedback form where students could add notes on the experiments (e.g. unclear instructions, difficulty, etc.). This written feedback was analysed to revise both the experimental setups and instructional materials. Subsequent testing rounds took place in both indoor and outdoor settings.

6 ▪ Students' knowledge and questions related to glaciers

To gain insights into students' prior knowledge and their questions related to glaciers, a structured feedback tool was employed during both the indoor and outdoor lab phases. At the beginning of the sessions, students were given color-coded cards. On one set of cards, they wrote down what they already knew about glaciers; on the other, they noted any questions they had on the topic. The responses were transcribed, clustered and analysed using qualitative content analysis, following the approach described by Kuckartz [2014].

In total, 83 students from six school groups participated in a structured pre-lab activity. The analysis of prior knowledge revealed 203 total entries, categorized into domains such as characteristics, decline, ice, location, water, formation, and usage. As shown in Table 3, the most frequent associations fell into the "Glacier Retreat" category. While some students explicitly mentioned climate change as the cause, many responses remained vague (e.g., "glaciers are melting"). Only a small number of responses addressed the consequences of glacier retreat. The second largest category was the naming of glacier characteristics. Notably, many students referenced glaciers as reservoirs of water and drinking water, possibly informed by media coverage of glacier retreat. Several misconceptions were also noted, including the idea that glaciers are habitats for animals or are directly linked to avalanches. On the one hand, many students associate glaciers with alpine regions; on the other hand, 12 students stated that glaciers are icebergs. Overall, the data indicate a limited and fragmented knowledge base.

In addition to prior knowledge, students contributed 130 questions related to glaciers and alpine regions. As shown in Table 4, the majority of questions focused on formation processes, basic facts, and the decline of glaciers (110 in total). Many students asked how glaciers were formed (N = 29) or how old they are (N = 15). A large number of questions also addressed factual aspects (N = 33), such as the number of glaciers, size, or location of glaciers.

Many students showed concern about glacier retreat (N = 30), asking how long glaciers will persist, what consequences their melting might have, and what could be done to prevent it. Five students expressed doubt or uncertainty about glacier retreat itself, revealing a need for clarification and more comprehensive information.

These findings raise important questions for science education and science communication, particularly regarding how fragmented knowledge and misconceptions can be addressed through outdoor and digital learning formats. Students' associations with glaciers were strongly influenced by media narratives, especially recurring images of glacier retreat in public discourse. While this generated awareness of climate change, it also produced

Table 3. Presentation of the collected prior knowledge and classification into categories (6 student groups with a total of 83 students).

Category	N	Subcategory	N
Glacier Retreat	50	Caused by Climate Change	29
		Unspecific	16
		Consequences of Decline	5
Characteristics	49	Glaciers are formed from snow	18
		Cold	13
		Crevasses	5
		Avalanches	4
		Glacier Movement	3
		Age	2
		Carbon Dioxide Storage	2
		Climate	2
Ice	42	Consisting of Ice	24
		Glaciers are Icebergs	12
		Permanent Ice Surface	3
		Ice Surface	3
Location	21	Alpine	21
Water	19	Water Storage	10
		Consists of drinking water	9
Formation	9	Duration	6
		Material	3
Usage	8	Sports	8
Habitat	3	Animals and Plants	3
Facts	2	Facts	2
Sum	**203**		**203**

fragmented knowledge and misconceptions (e.g., equating glaciers with icebergs). For science education, this highlights the importance of integrating glacier-related topics more into science lessons. The prevalence of vague or fact-based questions suggests that students often lack the conceptual tools to situate glaciers within broader climate systems. This is where our project comes in, enabling people to experience the glaciers either on site or with the help of virtual reality. At the same time, however, important facts and concepts need to be conveyed through active engagement.

7 ▪ Structure and implementation of the outdoor glacier lab

The outdoor glacier lab was implemented as a half-day program and piloted with four Austrian middle and upper school classes over four consecutive days. The students had at least basic scientific skills. The topic of glaciers is rather underrepresented in Austrian schools, and the students had little to no prior knowledge of the subject. The outdoor lab is located in the Dachstein region of Austria, which includes three glaciers: the Hallstätter Glacier, the Schladminger Glacier, and the Gosauer Glacier. While the digital learning

Table 4. Questions.

Category	N	Subcategory	N
Formation	47	Formation Process	29
		Age	15
		Human Influence on Glacier Formation	3
Facts	33	Number	5
		Size	5
		Living Beings	5
		Properties	12
		Location	6
Decline	24	Time	7
		Consequences	6
		Things to do Against Glacier Melting	4
		Doubts About Glacier Melting/Need for Further Information	5
		Causes	2
Importance	11	Importance of Glaciers	11
Water	8	Glaciers as Water Source	8
General	7	Composition	5
		Characteristics of Glaciers	2
Sum	**130**		**130**

environment developed in the project focuses on the larger Hallstätter Glacier, the field-based activities are conducted on the Schladminger Glacier due to its proximity and suitability for group visits. The Schladminger Glacier is a small glacier near the mountain station of the Dachstein cable car and can be reached easily from the station. As a touristic site, it offers flattened and crevasse-free walking paths, making the area suitable for student activities. No alpine guides are required, and the site poses minimal risk, even under changing weather conditions.

The outdoor lab is part of a collaboration with the Dachstein cable car company, which supports the project by providing free transport for participating school classes. Upon arrival, students receive a laboratory backpack containing materials and a lab booklet with instructions and explanations for each station. The activities are structured as guided, station-based learning, with students rotating in small groups through a series of thematic experiments. Depending on weather conditions, the stations are located either near the glacier tongue, at the proglacial lake, or in the area surrounding the mountain station. All activities take place outdoors, without fixed infrastructure. Key scientific phenomena investigated during the lab include, among others, the characteristics of glacier ice, cryoconite collection and meltwater conductivity. Furthermore, current research topics such as acid mine drainage and the presence of heavy metals in glacier water [Spitzer et al., 2024], as well as the solubility of carbon dioxide in glacier water and carbon capture through chemical weathering [Spitzer, 2025], are explored.

During one test phase, students also worked alongside researchers to take microbial samples from the ice, which were later incubated in a laboratory setting. Additionally, high-altitude physical effects are explored through simple experiments on boiling point and air pressure or are experienced hands-on using a PET bottle during the cable car descent. The program concludes with a visit to the “Ice Palace,” a tourist-accessible tunnel within the glacier, where students observe ice layering and discuss glacial formation processes. A laboratory booklet provides an overview of the stations and enables the students to continue their work back at school (e.g. analysing the collected cryoconite). It contains detailed experiment instructions, refers to the digital learning environment, and provides space for notes and observations.

8 ▪ Complementing the lab: insights from the digital learning platform

In parallel to the outdoor lab, a bilingual digital learning environment (German and English) was developed to complement and expand the glacial learning experience. QR codes in the lab booklet link directly to the digital scenes, enabling hybrid or asynchronous use. While the field-based activities take place on the Schladminger Glacier, the virtual environment focuses primarily on the Hallstätter Glacier, the largest glacier in the Dachstein region. Beyond its size, the Hallstätter Glacier holds historical significance, having been extensively documented by Friedrich Simony, a 19th-century scientist and early pioneer of glacier research in the Eastern Alps.

To provide a meaningful glacier experience for students unable to visit a glacier in person, a series of 360° panoramic images was produced and assembled into an interactive virtual glacier walk. The platform is also designed to be compatible with Virtual Reality (VR), allowing students to experience glacier environments using VR headsets. Users can also navigate the environment via an aerial image, in which various scenes are marked and linked to immersive panoramas (see Figure 3). Each scene focuses on a particular phenomenon with a corresponding topic addressed in the outdoor lab. To provide a broader glaciological perspective, the learning platform also includes scenes from a polar glacier, the Steindalsbreen near Tromsø in Norway.

9 ▪ Conclusion and outlook

The GlacierXperience project demonstrates how glacier environments can be transformed into outdoor laboratories that foster climate literacy, provide authentic encounters with scientific phenomena, and strengthen students’ engagement with climate change. By focusing on upper secondary school students, the project addressed a target group that is both scientifically literate enough to engage with glaciological phenomena and at a developmental stage when personal worldviews and future-oriented decisions are being shaped. The results of our pilot implementations show that students entered the project with fragmented knowledge and misconceptions but were able to deepen their understanding of glacial dynamics and their societal implications through active, hands-on learning.

From a science communication perspective, the project illustrates how dialogic, participatory formats can bridge research and education, enabling students to move beyond passive reception towards active inquiry. At the same time, the integration of digital tools extends the experience beyond the glacier site, offering preparation and reflection opportunities that make the outdoor lab accessible in classroom contexts. This hybrid approach contributes to a more robust form of climate literacy, linking local, tangible phenomena with global processes.

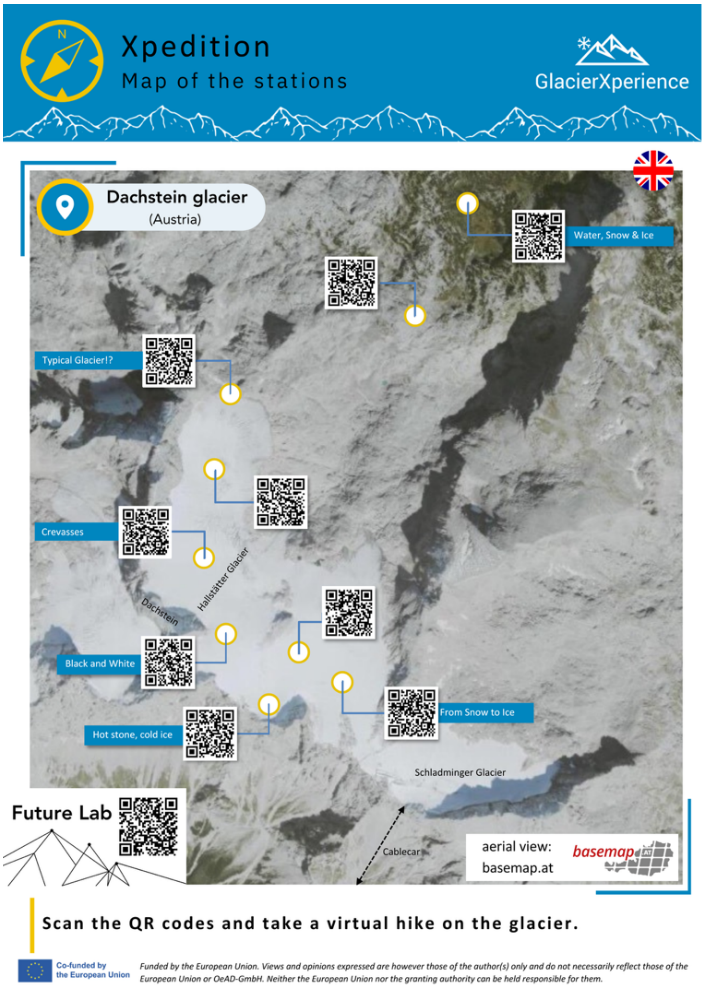

Figure 3. Map and and quick access to digital learning environment (https://glaciereducation.com/).

The project was made possible through close collaboration with the Dachstein cable car company, which ensured logistical feasibility and safe access to the glacier for school groups. The glacier lab was successfully piloted in summer 2024 and continued in 2025. Building on the analysis of students' prior knowledge and questions, future iterations will place greater emphasis on integrating current alpine and polar research. The lab booklet is being revised accordingly, with each experiment accompanied by a new section titled "A Look at Research" and QR codes linking to scientific publications and communication formats. These open-access materials are tailored to the needs of upper secondary school students and will allow the project to scale beyond individual excursions (see Figure 4). Overall, "GlacierXperience" illustrates the broader potential of outdoor labs in extreme environments as vehicles for science communication and climate education. What began as an idea for on-site learning has developed into a scalable, research-informed approach that combines experiential and digital learning to support students in engaging critically with climate change. Thanks to the hybrid design of the project (outdoor laboratory and virtual learning environment), it can also be implemented in regions without glaciers.

Figure 4. Example of the Labbook.

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