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Capacity building in geospatial analysis through international cooperation in Pakistan

Davide Fugazza[1], Antonella Senese[1*], Anees Ahmad[1], Blanka Barbagallo[1], Marco Casu[2,3], Francesco Dessì[2], Riaz Ul Hassan[4], Mohammad Aurang Zaib[4], Sadia Munir[4], Arif Hussain[4], Maria Teresa Melis[2] and Guglielmina Adele Diolaiuti[1]

*Correspondence:
Antonella Senese
antonella.senese@unimi.it
[1]Department of Environmental Science and Policy, Università degli Studi di Milano Statale, Via Celoria 10, 20133 Milano, Italy
[2]Department of Chemical and Geological Sciences, University of Cagliari, Monserrato, Cagliari, Italy
[3]Sapienza Università di Roma, Roma, Italy
[4]EvK2CNR Pakistan, Italian K2 Museum, Skardu, Gilgit Baltistan, Pakistan

Abstract

This study aims to evaluate the effectiveness of a multi-phase educational model in geoscience training implemented within an international cooperation framework. In the framework of the Glaciers & Students project (2021–2024), funded by the Italian Ministry of foreign affairs and International Cooperation and the Italian Agency for development cooperation and executed by the United Nations Development Programme (UNDP), we developed an innovative educational model for the development of geospatial skills in the context of international scientific cooperation. Specifically, the project targeted Pakistani university students with the goal of strengthening their competences in GIS (Geographic Information Systems) and remote sensing through a structured, multi-phase training strategy. To overcome the limitations of traditional short-term capacity-building approaches, the program was designed around three integrated phases: (i) asynchronous e-learning, (ii) in-person training in Pakistan with Italian researchers, and (iii) a nine-month remote mentoring phase focused on applied geospatial analysis. As a final application, participants contributed to a didactic glacier inventory for Pakistan. While not validated for scientific use, this inventory served exclusively as an educational tool to apply technical skills in a realistic context, given the country's reliance on meltwater from high-mountain glaciers. The study evaluated learning outcomes through anonymous self-assessment tests and satisfaction surveys. Supported by statistical analyses, results showed substantial improvements in participants' technical skills, confidence, and career orientation, professional motivation, and inclusivity. The project demonstrates how international cooperation can deliver scalable, inclusive, and context-adapted geoscience education. It also provides a transferable model for climate-related capacity building, aligned with the Sustainable Development Goals.

Keywords Pakistan, International cooperation, Blended learning, Geospatial education, Remote sensing, Educational evaluation

1 Introduction

International cooperation projects play a strategic role in fostering scientific and technological capacity in partner countries [1], with education and training being essential drivers of long-term socio-economic development [2]. Despite this potential, training initiatives in development cooperation often lack continuity, post-training mentorship, and structured evaluation frameworks [3, 4]. In geospatial sciences, while blended learning is recognized as effective [5–7], few documented cases exist in low- and middle-income country (LMIC) contexts, and even fewer include formal evaluation [8–10]. This study addresses this gap by providing an empirical assessment of a multi-phase educational model implemented in Pakistan, designed to strengthen GIS and remote sensing skills through a structured pathway combining e-learning, in-person training, and remote mentoring.

Higher education in geospatial sciences presents both a challenge and an opportunity for LMICs. While the growing availability of satellite data, cloud platforms, and open-source tools has lowered barriers to access, significant disparities remain in terms of pedagogical models, faculty expertise, and digital infrastructure. International initiatives such as NASA's SERVIR [11], UNOSAT [12], and Digital Earth Africa [13] have helped improve access to data and training, yet they primarily target professionals and policymakers rather than university students. As a result, there is a need for educational models tailored to higher education in LMICs that can build durable geospatial competences and promote local ownership of environmental knowledge.

Existing training programs in technical cooperation often adopt short-term, intensive approaches (e.g., field missions, workshops, or Erasmus+ exchanges [14]), which rarely translate into sustainable learning outcomes. Conversely, distance-only formats, while scalable, can be hindered by infrastructural limitations, language barriers, or low digital literacy.

Moreover, capacity-building projects in science and technology are seldom assessed through structured evaluation frameworks. Unlike infrastructure interventions, which are typically monitored through well-defined indicators, training activities are often reported descriptively (focusing on the number of participants or activities) without evaluating actual learning gains or long-term impacts [15–18].

To address these gaps, this study evaluates a multi-phase training model developed within the "Glaciers & Students" project, implemented between 2021 and 2024 in Pakistan. Funded by the Italian ministry of foreign affairs and international cooperation and the Italian agency for development cooperation and coordinated by Italian universities in partnership with the NGO (non-governmental organization) Ev-K2-CNR, the program aimed to enhance geospatial skills among university students through a structured pathway comprising asynchronous e-learning, in-person instruction, and remote mentoring. A follow-up module delivered in 2025, under the Water for Development (W4D) project, further expanded the training by introducing UAV-based environmental monitoring.

The program culminated in a collaborative exercise to produce a didactic glacier inventory for Pakistan, used solely for educational purposes to consolidate remote sensing and GIS skills. Scientific validation of the inventory will be addressed in a separate publication.

This study contributes to the literature by offering an empirical evaluation of a structured, blended learning pathway in an LMIC setting. It responds to recent calls for evidence-based approaches in geoscience education within development cooperation [15], and aligns with Italy's legal and institutional framework for cooperation (Law 125/2014) [19], which emphasizes inclusive growth, environmental sustainability, and youth empowerment.

By documenting learning outcomes, student engagement, and perceived impacts, this research shifts the focus from scientific outputs to human capital development, contributing to the long-term sustainability of geoscientific knowledge and practice in LMICs.

More broadly, the project aligns with a growing trend in international cooperation where science education and technology transfer have emerged as strategic priorities. Italian universities, often in collaboration with NGOs and international organizations, have implemented cooperation projects involving scientific training and environmental monitoring in regions such as Central Asia, East Africa, and South America. The "Glaciers & Students" project fits within this trajectory, representing a shift from short-term knowledge transfer toward a more integrated and replicable model of geoscience education. This approach aligns with the Sustainable Development Goals (SDGs) and the United Nations 2030 Agenda, particularly in relation to Quality Education (Goal 4), Climate Action (Goal 13), and Partnerships for the Goals (Goal 17) [20].

The following sections detail the structure and methods of the "Glaciers & Students" project (Sects. 2 and 3), present the main findings (Sect. 4), and discuss their implications in light of the literature and future prospects (Sections 5 and 6).

2 Structure and phases of the "Glaciers & Students" project

The "Glaciers & Students" project was conceived as an interdisciplinary capacity-building initiative funded by UNDP and coordinated by the NGO Ev-K2-CNR in collaboration with the University of Milan (UNIMI) and the University of Cagliari (UNICA). Its primary goal was to strengthen geospatial and environmental competences among Pakistani university students through a three-phase blended learning model, combining online instruction, in-person training, and remote mentoring. It builds on previous Italian cooperation efforts in Pakistan (e.g., the SEED and SHARE-PAPRIKA projects [21]), while shifting the focus from scientific outputs to human capital development in geospatial science.

The training focused on glacier monitoring as a thematically relevant and technically demanding application of remote sensing and GIS. Glaciers in the Karakoram region serve as a critical freshwater source and are central to ongoing climate research due to phenomena such as the "Karakoram anomaly" [22–25]. Within this context, students engaged in the creation of a national glacier inventory, used exclusively as a didactic tool to apply acquired competences in a real-world setting. A separate publication will address the scientific validation of the inventory [26].

The training was structured in three main phases. The first phase 1 involved an asynchronous e-learning approach. 93 Pakistani bachelor students were selected through Ev-K2-CNR's university network and followed pre-recorded video lectures (in English) on remote sensing, GIS, meteorology, and applied glaciology. The online modules included self-assessment tools and comprehension checks. In parallel, 90 Italian master's students received similar training through their university programs.

Table 1 Summary of the tiered training methodology applied in the glaciers & students project

Phase	When	Where	Who	How	Topic	Students	Evaluation
Phase 1	August-September 2022	Remotely (Pakistan)	Italian instructors	Asynchronous e-learning	Remote sensing, GIS, meteorology, glaciology	93 Pakistani students	Baseline questionnaire and self-assessment tests
Phase 2	2022–2023	Skardu, Gilgit, Baltistan	Italian instructors + Pakistani tutors	In-person training & fieldwork	Glacier monitoring, satellite image analysis	215 Pakistani students	Hands-on exercises, field data collection
Phase 3	2023	Remotely (Pakistan + Italy)	Italian tutors	Remote mentoring	Collaborative glacier mapping	60 Pakistani + 30 Italian students	Applied mapping tasks, online tutoring

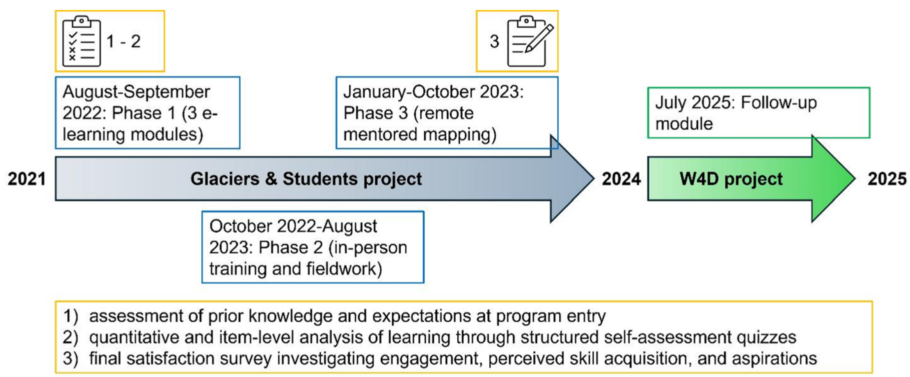

Fig. 1 Timeline of the Glaciers & Students project (2021–2024, blue arrow) and the follow-up Water for Development project (2025, green arrow), showing the three training phases (blue boxes), the continued educational pathway (green box), and evaluation activities (orange boxes)

During the second phase, which involved in-person training and fieldwork, Italian instructors conducted face-to-face lessons and supervised practical activities in Pakistan. A total of 215 students participated, including the initial 93 students from the e-learning phase and many others who joined during the on-site sessions. Although several participants had not followed the theoretical modules of Phase 1, they were nonetheless included in the practical sessions. This decision reflected the project's commitment to inclusivity and knowledge dissemination in geosciences and geospatial analysis, particularly in low-resource settings. The approach enabled students from diverse academic backgrounds to benefit from hands-on training in GIS and remote sensing.

During the third phase (i.e. remote mentored mapping), 60 Pakistani and 30 Italian students engaged in a nine-month collaborative mapping project, focusing on the delineation of glaciers from satellite imagery using cloud-based GIS tools. Tutoring was provided remotely through periodic online meetings and asynchronous exchanges. Students worked individually or in small groups, developing applied skills in data processing, visualization, and collaborative analysis.

Table 1 summarizes the teaching strategy across the three phases and two student populations and Fig. 1 shows the timeline of the training program and evaluation activities.

The same 60 Pakistani students (who were engaged in remote collaborative mapping activities) later participated in a follow-up module in 2025, under the Water for Development (W4D) cooperation project. This advanced course introduced UAV-based environmental monitoring, strengthening the continuity of the training and expanding its thematic scope. This progression illustrates the project's commitment to long-term educational continuity and capacity building.

In addition to Pakistani students, Italian students, enrolled in master's programs at the Universities of Milan and Cagliari, followed equivalent theoretical and practical modules, particularly during Phase 3, where they worked alongside Pakistani peers in collaborative mapping activities. Their involvement was essential in fostering intercultural exchange and peer-to-peer learning.

The project emphasized inclusivity, engaging Pakistani students from diverse backgrounds and promoting gender equity. The Glaciers and Students project structure enabled the implementation of a multi-level evaluation strategy, assessing both immediate learning outcomes and longer-term professional impacts.

The following section details the methods used to evaluate the effectiveness of the training program.

3 Methods

This section presents the methodological protocol adopted to evaluate the educational effectiveness of the "Glaciers & Students" program. The evaluation was designed to be replicable, modular, and adapted to development cooperation contexts, and follows a structured, three-phase model aligned with the training pathway (Fig. 2).

The protocol is organized as follows:

- Phase 1 (e-learning): Evaluation of prior knowledge and conceptual learning through self-assessment tests after each module.
- Phase 2 (in-person training and fieldwork): Since no formal tests or surveys were administered during this phase, students' learning progress was assessed qualitatively through direct classroom observation and informal discussions. Instructors monitored engagement, responsiveness, and conceptual understanding by interacting with students during lectures and practical sessions. This formative approach allowed the teaching team to identify areas of difficulty, adapt instruction accordingly, and provide targeted support where needed.

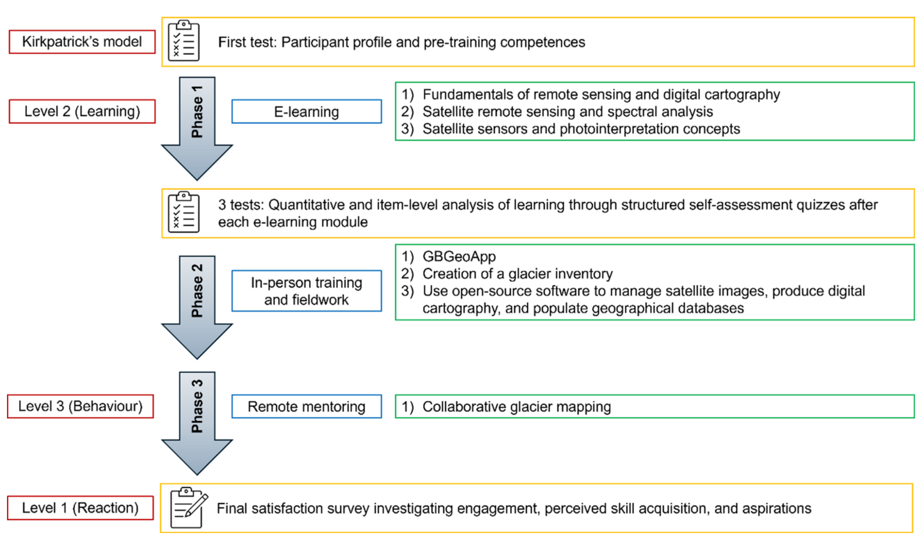

Fig. 2 Overview of the methodological protocol, showing the three training phases (blue), Kirkpatrick model levels (red), training topics (green), and assessment tools (orange)

- Phase 3 (mentored mapping activities): Analysis of behavioral engagement and perceived skill application, through performance in mapping tasks and a final satisfaction survey.

Each phase included dedicated evaluation tools (e.g., questionnaires, tests) and was aligned with specific levels of the Kirkpatrick Model (Reaction, Learning, Behaviour). Data were analyzed using a combination of descriptive and inferential statistics, and the overall process was framed within a Results-Based Management (RBM) logic to ensure coherence between objectives, activities, and outcomes.

The following subsections describe in detail the evaluation design, the data collection tools, and the statistical methods used to assess the impact of the program on geospatial skill development, student satisfaction, and inclusivity.

3.1 Evaluation design and tools

The evaluation aimed to measure learning gains, engagement, and perceived impact using a mixed-methods approach. Figure 1 illustrates the timeline of training phases and evaluation activities, ensuring transparency in the temporal structure of the process. The methodology combined: (i) baseline questionnaire to assess prior knowledge and expectations, (ii) structured self-assessment quizzes after each e-learning module, and (iii) a final satisfaction survey (Fig. 2). Quantitative data were analyzed using descriptive statistics and inferential tests (chi-square, t-tests, Pearson correlation), complemented by effect size calculations (Cohen's d, Cramer's V) to strengthen interpretation. This design aligns with Kirkpatrick's Four-Level Model [27–29] and Results-Based Management principles [30, 31], providing a structured framework for evaluating educational effectiveness.

The Kirkpatrick's model is commonly used in education and professional development programs. Specifically, as shown in Fig. 2, Level 1 (Reaction) was assessed through the final satisfaction questionnaire, Level 2 (Learning) was captured via self-assessment quizzes administered after each e-learning teaching module, Level 3 (Behaviour) was observed through students' participation in real-world mapping tasks and qualitative feedback about skill application, and Level 4 (Results) was not quantitatively measured, but student aspirations and post-training engagement suggest potential long-term benefits.

Although the involvement of Italian students was essential in fostering intercultural exchange and peer-to-peer learning, their feedback and test results were not included in the present assessment due to differences in baseline competences and academic pathways.

The questionnaires used in this study were designed drawing inspiration from validated instruments such as the Course Experience Questionnaire (CEQ, see [32]) and the Student Perceptions in Earth and Space Sciences (SPESS, see [33]) framework, commonly used in geoscience education research. While not formally validated, these tools aimed to capture students' prior knowledge, engagement, and perceived learning gains across different phases of the training.

In addition, this approach aligns with Results-Based Management (RBM) principles promoted by agencies such as UNDP and JICA (Japan International Cooperation Agency), which encourage the use of adaptable and participatory evaluation tools in development contexts [30, 31]. It also reflects recent trends in geoscience education, where questionnaire-based methods are increasingly used to assess inquiry-based learning, GIS skill acquisition, and the impact of blended learning formats in resource-constrained environments.

Accordingly, we developed activity-specific questionnaires that we distributed to the students. All the questionnaires have been developed using the Microsoft Forms application (Microsoft© and Office 365© educational license provided by UNIMI to all teachers and students). The first questionnaire was distributed at the beginning of the training activity. The other questionnaires have been proposed after their participation in each project phase. The first questionnaire was developed to find out the basic knowledge level of the students in the Glaciers & Students project prior to the courses delivered in order to understand their background (e.g. types of schools and university courses attended in Pakistan), their prior knowledge of glaciers, hydrology, meteorology and GIS, and their expectations for educational and professional development.

Questionnaires were then developed and proposed for the individual teaching units delivered, to assess the students' understanding (i.e. training tests) and enjoyment of the course. The training tests on the different topics covered by the course were proposed at the end of each teaching module. Each test consisted of multiple-choice questions assessing conceptual understanding of contents explained during the lectures. Responses were scored automatically, with one point assigned for each correct answer.

Finally, a survey was conducted to assess participants' satisfaction with the entire training program (phases one, two, and three).

To analyze quantitative data collected across the training phases, we applied both descriptive and inferential statistical methods, aimed at identifying trends in performance, levels of satisfaction, and possible associations with demographic or participation variables (see Table 2). To ensure reproducibility, Table 2 summarizes the statistical tests applied, the variables analyzed, and their objectives. Analyses were conducted in Python (pandas, scipy), with significance set at $p < 0.05$ and effect sizes (Cohen's d for t-tests, Cramer's V for chi-square tests, and Pearson's r for correlations) reported alongside 95% confidence intervals. This workflow included data cleaning, descriptive statistics, inferential tests, and effect size computation to provide a transparent and replicable evaluation framework (Table 2).

Table 2 Statistical tests applied to questionnaire data, showing the variables compared and the objective of each analysis

Statistical test	Variables compared	Objective
Chi-square test	Gender vs. Satisfaction	Assess association between categorical variables
t-test	Full vs. Partial Participation	Compare satisfaction levels across groups
t-test	Used Skills vs. Not Used	Evaluate impact of skill application on satisfaction
t-test	Only First Phase vs. Others	Assess effect of participation pattern
t-test	Prior Experience vs. No Experience	Compare satisfaction based on prior exposure
Pearson correlation	Age vs. Satisfaction	Assess linear relationship between age and satisfaction

All tests were performed in Python (pandas, scipy), with significance set at p < 0.05 and effect sizes reported alongside 95% confidence intervals

The following subsections detail the evaluation design applied to each phase of the training program, aligning learning objectives with the tools and metrics adopted to assess their effectiveness. Below we detail the structure of the teaching units conducted, their characteristics, the proposed questionnaires, and the students' responses.

3.2 Phase 1 – E-learning: introduction to remote sensing and cartography

The first project phase was dedicated to remotely providing all students intercepted by EvK2CNR in four major Pakistani universities with the theoretical basics of remote sensing and digital cartography. Ninety-three (93) students took part in this phase. For this purpose, instructional videos (mp4 files) were prepared in English illustrating the basic concepts with the help of images, graphics, and photos. The videos were recorded in Italy and sent by means of wetransfer.com webapp to Pakistan for asynchronous use by the students. In fact, many did not and still do not have an effective internet connection at home, making synchronous streaming impossible.

The videos were developed specifically for the Glaciers & Students project, divided into teaching modules of 15–20 min each and created to proceed in sequential order so that each preceding video is the cultural basis for the content provided in the subsequent video. The choice of videos limited to a maximum of 20 min is supported by the fact that beyond 20 min, many authors report that students' attention spans decrease [34]. Even though there are authors who debate the robustness and truthfulness of this time window [35], we decided to develop short modules in order to be able to convey concepts and knowledge in a more effective way to a more attentive and interested audience.

The students who took part in the first project phase were first asked to fill out a cognitive questionnaire, to find out who the Glaciers & Students project students were and what their educational and work expectations were. This first questionnaire, in English, can be filled out online from one's own smartphone thanks to the Microsoft Forms interface open to anyone who has the invitation link to the test (without the need for office licenses, specific e-mail domains or download of apps) and can be completed in about 10 min. Table 3 reports the questions proposed in the first questionnaire; this latter can also be viewed directly in Microsoft Forms by accessing the link https://forms.office.com/e/eg6cGvYc7f.

After completing the initial cognitive questionnaire, Pakistani students accessed the mp4 audio lessons asynchronously. At the end of each teaching module, self-assessment questionnaires were administered to evaluate the knowledge acquired. These questionnaires were designed to be accessible from any device without requiring an app, ensuring anonymous participation, immediate feedback on scores and mistakes, and the opportunity to retake the test to reinforce learning. If a student scored poorly or insufficiently, they were encouraged to review the relevant mp4 lesson and attempt the test again to verify their improvement.

The self-assessment questionnaire scores ranged from 0 to 32, following the Italian grading system (out of 30). A passing score was 18/30 or higher, while the maximum distinction was awarded at 30/30 or higher. The first training module introduced participants to the fundamentals of remote sensing and digital cartography. Students learned about satellite imaging technology, how satellites capture images of Earth's surface, and the tools available for analyzing satellite data. They also gained practical experience in digital cartography, developing skills to create detailed and accurate maps using

Table 3 Questions proposed to the students attending the "Glaciers & Students" project at the beginning of the training activities to get to know them, their basic knowledge and their expectations (see also https://forms.office.com/e/eg6cGvYc7f)

Question number	Question	First proposed option (if any)	Second proposed option (if any)	Third proposed option (if any)
1	Please insert your name	Open question		
2	Please insert your surname	Open question		
3	Please insert the University you are attending and the course (Ba or MS)	Open question		
4	Please insert your age	Open question		
5	Please insert your e-mail	Open question		
6	Have you already studied remote sensing?	Yes	No	
7	Have you already studied cartography?	Yes	No	
8	In case you answered yes, have you already applied remote sensing and cartography? Can you describe how and the results you obtained?	Open question		
9	Have you already studied glaciology?	Open question		
10	What do you expect from this course and the other activities included in the "Glaciers and Students" project?	Open question		
11	Do you think that by taking part in this project you will improve your skills and competences in view of your professional future?	Yes	No	Maybe
12	Do you want to tell us any particular needs or expectations so that we can take them into account for the next teaching and research activities?	Open question		

specialized software, facilitating effective spatial data visualization and analysis. The first self-assessment questionnaire is available at this link https://forms.office.com/e/Bm9YbKgLRB.

The second training module focused on satellite remote sensing and spectral analysis. At the end of this session, students were invited to complete the second self-assessment questionnaire, available at this link https://forms.office.com/e/bwHh28iDM1.

The third training session primarily covered the technical details of satellite sensors and their resolution, alongside advanced digital image interpretation methods. The third self-assessment questionnaire is available here https://forms.office.com/e/0gxDk09t6M.

3.3 Phase 2 – In-person training and fieldwork in Pakistan

Building on the foundational knowledge acquired through the remote modules, the second phase introduced hands-on learning and fieldwork activities conducted directly in Pakistan, with sessions held in October 2022, in May and August 2023. In October 2022 the training was performed at the University of Baltistan (Skardu) and at the Karakorum International University (KIU) of Gilgit. It took three days per university; 2 days were spent in the GIS lab and one on the field to collect geolocalized data with the GBGeoApp. This is an application for mobile developed by the University of Cagliari in the framework of the collaborative projects with EvK2CNR to support with a friendly tool the acquisition of data in the field [36]. This first training activity was led by a professor from the University of Cagliari. She had a long and robust experience in training activities under the umbrella of cooperation and development programs. In May, the training took place again at two universities: Karakorum International University and Baltistan University (two weeks per university). Around 115 participants from various departments, including Environmental Sciences, Forestry, Earth Sciences, and Disaster Management, attended. The course, led by a University of Milan scientist from Pakistan, focused on glacier characteristics, monitoring techniques, and the use of satellite remote sensing in glacier inventory.

In August 2023, another training was held exclusively at Karakorum International University, attended by approximately 100 students from other universities. One Italian scientist from the University of Milan taught the course. Both sessions included practical activities in classrooms equipped with PCs, where students learned to use open-source software to manage satellite images, produce digital cartography, and populate geographical databases.

The training content included:

1. Definition and importance of glaciers: Introduction to glaciers, their role in freshwater resources, and their importance for studying climate change and ecosystem dynamics.
2. Monitoring techniques: Overview of field surveys, ground-based measurements, and the advantages of satellite remote sensing for glacier monitoring.
3. Satellite Remote Sensing: Explanation of the basics of remote sensing, satellite technologies, and the different types of sensors and data supply channels.
4. Characteristics and resolution of satellite imagery: Detailed explanation of satellite image resolution, focusing on the Sentinel Copernicus mission and practical use of software tools like SNAP and QGIS.
5. Spectral-based classifications: Introduction to indices like NDVI, NDSI, and NDWI for characterizing vegetation, snow, and water bodies in satellite imagery.
6. Object-Based Image Analysis (OBIA): Training on OBIA, which groups pixels into meaningful objects, offering advantages over pixel-based methods. Practical exercises with QGIS followed.
7. Image classification and cross-checking: Hands-on classification of satellite images, using spectral-based methods and OBIA, with validation against reference data like Google Images and previous glacier inventories.

At the end of the classroom training, students had the chance to join Italian tutors in fieldwork, installing automatic weather stations on glaciers to collect data on glacier melt modelling. Some Pakistani students participated in these activities, contributing to the Glaciers & Students project's instrumental network.

Overall, the training provided valuable knowledge and practical skills in glacier monitoring, satellite remote sensing, and data analysis. Participants gained hands-on experience with tools like SNAP and QGIS, and the interdisciplinary nature of the course encouraged collaboration, future research, and the exchange of ideas. The training successfully equipped students to contribute to glacier research, monitoring, and decision-making, improving understanding of climate change impacts on glaciers and ecosystems.

3.4 Phase 3 – Collaborative glacier mapping

The skills developed during the in-person sessions of the second phase were subsequently consolidated through a mentored, applied mapping activity, which forms the core of the third phase.

The third phase of the "Glaciers & Students" project was designed as a practical and collaborative exercise in remote sensing and digital cartography. Pakistani students, after completing prior training modules, were invited to apply their newly acquired skills in a real-world context by contributing to the delineation of glacier features across northern Pakistan. This activity was conceived and implemented as a didactic exercise. Its primary aim was to reinforce technical competences in satellite image analysis, GIS-based mapping, and collaborative data processing.

Students worked in small groups, supported by Italian tutors through periodic online meetings. The workflow included satellite data preparation, image segmentation, and classification using spectral indices such as Normalized Difference Snow Index (NDSI). The tools and methods used (i.e. Google Earth Engine, QGIS, and cloud-based data sharing) were selected for their educational value and accessibility. Italian students from UNIMI and UNICA participated in parallel, fostering intercultural exchange and peer learning.

The glacier inventory was developed using optical data from the European Space Agency's Sentinel-2 satellites, chosen for their ability to provide consistent coverage with high spatial resolution, suitable for glacier identification. The methodology was divided into two main parts: satellite data preparation and glacier classification [37]. Here are the main phases of the work:

1) Satellite Data Arrangement: The base data used for classification included Digital Elevation Models (DEM) and satellite optical imagery. The DEM, such as the ALOS AW3D30 global model (30 m resolution), was used to divide Gilgit Baltistan into hydrographic basins, focusing the analysis on areas containing glaciers.
2) Glacier Recognition and Mapping: The data preparation involved creating a cloud-free, multi-spectral composite of the mountain range in northern Pakistan. This was achieved using Google Earth Engine to handle the large volume of Sentinel-2 data. Spectral indices (e.g. NDSI) were used to distinguish glaciers from other terrain features. Image segmentation techniques were applied to classify glaciers based on spectral, geometric, and textural properties, using various parameters such as scale factor, color, and compactness.

In the glacier classification phase, Pakistani and Italian students worked together within a GIS environment, with data uploaded to a cloud server for easy access. Each basin had four thematic data layers: the composite multi-band image, spectral indices, and shapefiles of polygons segmented at 250 m and 100 m Minimum Mapping Unit (MMU). Periodic online meetings supported the classification process, and existing glacier inventories and high-resolution satellite images helped refine the boundaries.

By the end of this phase, the Pakistan Glacier Inventory had been completed, mapping and describing more than 13,000 glaciers.

While the activity resulted in a preliminary glacier inventory (raw data available at [26]), this output is presented here solely as an educational product. Its scientific validation, including uncertainty analysis and comparison with existing datasets (e.g., RGI, GLIMS), will be addressed in a separate publication. The pedagogical value of this phase lies in its ability to simulate a research workflow, promote autonomy, and consolidate learning through applied practice.

This final practical phase not only enhanced technical competences but also set the ground for evaluating the program's overall impact, as discussed in the next section.

3.5 Final evaluation of the full training program

A survey was conducted to assess participants' satisfaction with the entire training program (phases one, two, and three) (Table S1). A detailed questionnaire was used to gather feedback (see https://forms.office.com/e/kwiRZQ9hhb). Similar to previous surv eys that evaluated students' understanding of the theoretical content, this questionnaire was anonymous.

The integration of self-assessment scores and post-training satisfaction data allowed us to triangulate learning outcomes with student perceptions. Descriptive statistics and inferential tests (e.g., t-tests, chi-square, correlation) were used to analyse these data, offering a more robust and comprehensive picture of educational impact. In addition, a composite satisfaction index was calculated to integrate the final satisfaction rating (1–5 stars) with binary responses to five key questions regarding the training experience. This composite index is not based on a validated psychometric instrument; rather, it was developed as an exploratory metric to synthesize multiple indicators of perceived quality within the scope of this study. The index was computed using anonymized questionnaire data and calculated as follows:

$$Composite\ satisfaction\ index = \frac{(satisfaction\ rating + \sum binary\ responses)}{1+n} \cdot 20 \quad (1)$$

where $n = 5$ is the number of binary questions.

4 Results

As outlined in Sect. 3, self-assessment tests captured Level 2 (Learning), while satisfaction surveys addressed Level 1 (Reaction) of the Kirkpatrick framework. The integration of these tools allowed a multi-dimensional interpretation of training effectiveness. Results confirm the robustness of the model, with progressive learning gains across modules and significant differences in satisfaction between participation groups.

4.1 Participant profile and pre-training competences

As introduced in Sect. 3.1, a preliminary baseline questionnaire was administered before the start of the training (corresponding to Level 0 – Context and Input in Results-Based Management logic). This tool collected demographic information, prior knowledge, and expectations, and was designed to help contextualize learners' backgrounds and readiness levels before entering the instructional pathway.

The survey, completed by 93 students, provided insights into their academic and demographic characteristics. The average age was 25.9 years (Fig. 3), with most

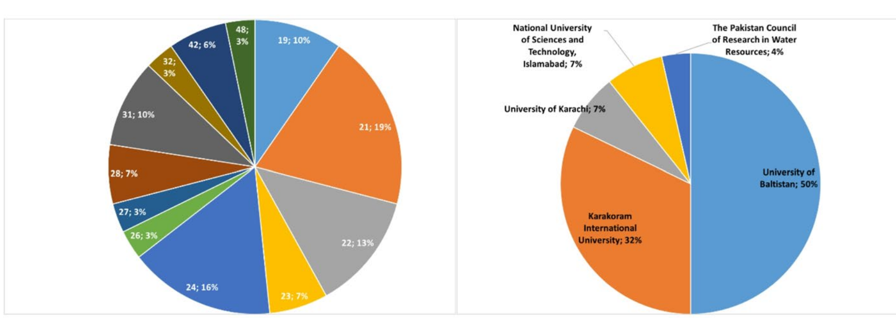

Fig. 3 Age (on the left) and institutional affiliation (on the right) distribution of respondents in the initial survey

respondents under 24. The majority came from the University of Baltistan and Karakoram International University (Fig. 3).

Prior exposure to key geospatial topics was limited (only 39% for remote sensing, 19% for cartography, and 35% for glaciology). Figure 4 shows a boxplot comparing age distribution based on prior experience in remote sensing, revealing slightly older age among experienced students, possibly indicating higher academic seniority.

Importantly, 90% of students believed the training would enhance their professional development. This result confirms the perceived relevance of the training initiative, a key condition for participant motivation and engagement in subsequent phases (corresponding to Level 1 – Reaction and indirectly, Level 3 – Behaviour of the Kirkpatrick's model).

All participants voluntarily shared email addresses for future contact, suggesting high initial trust and interest in long-term engagement, critical elements for cooperative training programs in LMIC contexts.

4.2 Performance in the first e-learning module on remote sensing and cartography

This section presents the results of the first self-assessment test, which was administered at the end of the initial asynchronous e-learning module, as described in Sect. 3.2. The test was designed to evaluate conceptual understanding of remote sensing and digital cartography, addressing Level 2 (Learning) of the Kirkpatrick framework.

The test, developed via Microsoft Forms and distributed online, consisted of 32 multiple-choice questions covering key topics such as electromagnetic radiation, atmospheric interactions, and spectral response. A score of 1 was awarded for each correct answer, and 0 for incorrect ones.

The average completion time was 35 min. The mean score was approximately 19 out of 30 with a maximum of 29. The results showed the following distribution: 38% of students scored below 18, indicating an insufficient understanding. 33% achieved a passing score (18–24). About 29% obtained high scores (25–29).

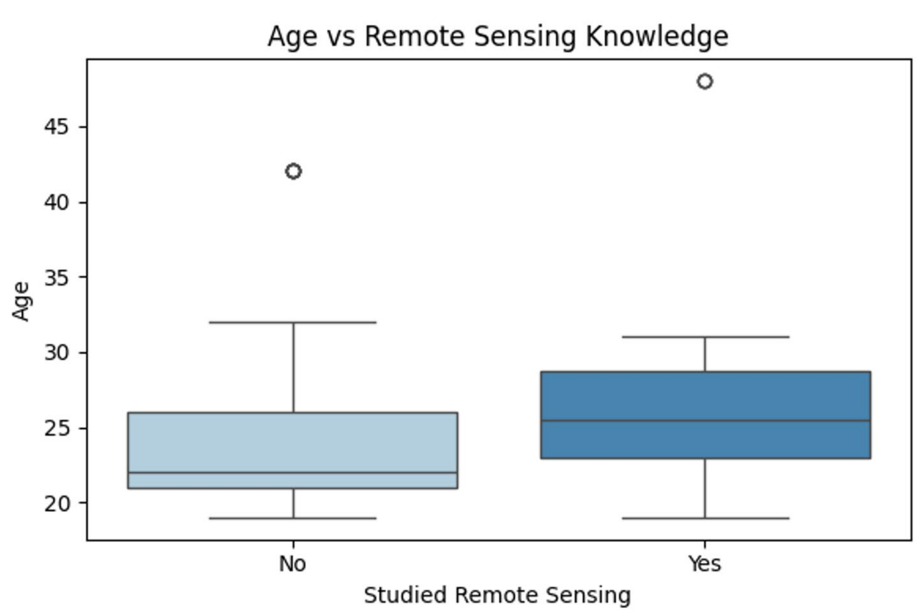

Fig. 4 Boxplot of student age distribution grouped by prior remote sensing experience

Figure 5 shows the item-level analysis of response accuracy. The highest success rates were recorded for questions related to: (i) definitions of remote sensing, (ii) the visible spectrum, (iii) electromagnetic wave properties, and i) types of scattering (Rayleigh, Mie, Nonselective). In contrast, lower accuracy was observed for questions on: (i) the infrared and microwave spectral regions, (ii) atmospheric windows, and (iii) reflection and absorption mechanisms.

These results confirm that students had a solid grasp of introductory concepts, but struggled with more abstract or technical topics, especially those requiring understanding of less intuitive physical processes. Based on this, instructors adjusted the content of subsequent modules (as described in Sect. 3.2) to include: (i) interactive simulations, (ii) analogy-based visual explanations, and (iii) additional focus on electromagnetic spectrum applications. These pedagogical adaptations were part of a continuous improvement approach aligned with Results-Based Management (RBM) principles and student-centered instruction.

4.3 Performance in the second e-learning module on satellite remote sensing and spectral analysis

This section reports the outcomes of the second self-assessment test, which evaluated students' understanding of satellite remote sensing and spectral analysis. The test was administered online at the end of the second asynchronous e-learning module, following the procedures described in Sect. 3.2. It contributed to evaluating Level 2 (Learning) of the Kirkpatrick framework, focusing on conceptual acquisition after the second e-learning module.

The test included 32 multiple-choice questions (each correct response was assigned 1 point), designed to assess comprehension of key geospatial topics such as satellite orbits, spectral signatures, and sensor typologies.

The average completion time was 38 min. The scores ranged from 11 to 32, with a mean of around 23 and a median close to 25, indicating a distribution slightly skewed toward higher values. However, 27% of participants scored below 18, which is considered insufficient (potentially reflecting gaps in prior knowledge or language-related difficulties). The standard deviation was ~ 8, suggesting moderate variability in student performance. 18% of students scored from 18 to 24 and 55% above 25, and 27% reached the maximum score (30 or more), suggesting strong comprehension of core concepts. This distribution supported the effectiveness of the teaching approach and materials used in

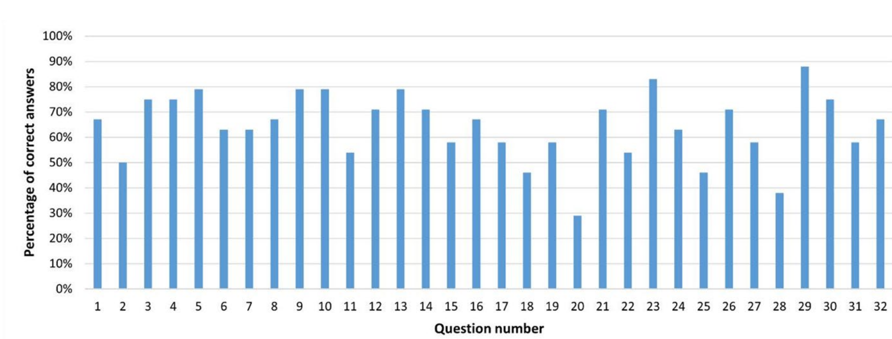

Fig. 5 Percentage of correct answers for each question in the first self-assessment test

the second module, while also highlighting a small subset of students who needed additional support or review sessions.

Figure 6 presents the percentage of correct answers per item. Students showed the highest accuracy in questions addressing chlorophyll reflectance, active vs. passive sensors, and satellite orbital parameters (e.g. nadir points, orbital periods). These results suggest effective assimilation of visual and spatial concepts. In contrast, lower performance was observed in questions involving more abstract or less intuitive topics, such as thermal infrared sensing and satellite revisit cycles.

Based on these findings, instructors decided to enhance future modules by introducing (i) interactive simulations of satellite paths, (ii) visual comparisons of spectral curves, and (iii) hands-on exercises with real satellite imagery. These interventions aimed to support students with diverse backgrounds and reinforce complex theoretical content through applied practice.

Overall, the results confirmed that students were progressing well through the educational pathway, with clear areas for targeted reinforcement.

4.4 Performance in the third e-learning module on satellite sensor and photointerpretation concepts

The third self-assessment test, described in Sect. 3.2, was used to evaluate students' competences in sensor technology and photointerpretation. The test was administered online at the end of the third asynchronous e-learning module. Similarly to the previous ones, it contributed to evaluating Level 2 (Learning) of the Kirkpatrick framework, focusing on conceptual acquisition after the second e-learning module. Below are the aggregated results and item-specific insights.

Respondents took an average of 31 min to complete this questionnaire. The scores ranged from 10 to 30, with a mean of 23/30, and a median of 27, and standard deviation of about 7. A significant number of students (70%) scored above 25, demonstrating solid understanding of remote sensing and aerial photography concepts. Conversely, a few (30%) scored below 18, suggesting difficulty with more advanced topics such as spectral resolution and photogrammetry.

As shown in Fig. 7, item-level analysis revealed generally strong performance, though areas requiring reinforcement were identified. These findings highlight the need for

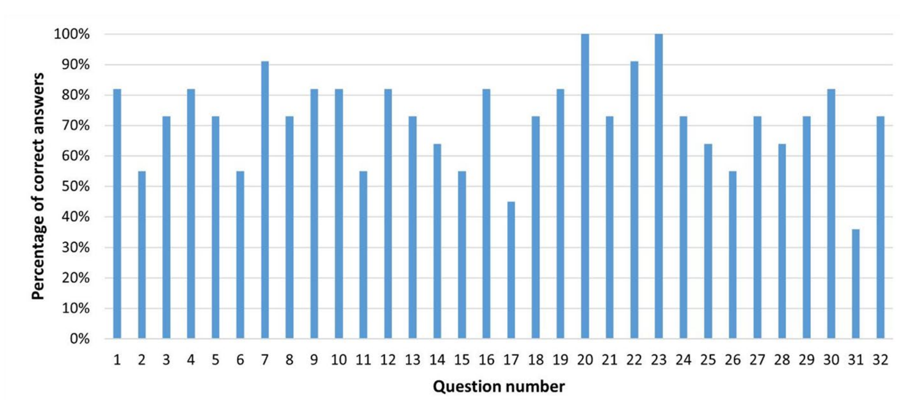

Fig. 6 Percentage of correct answers for each question in the second self-assessment test

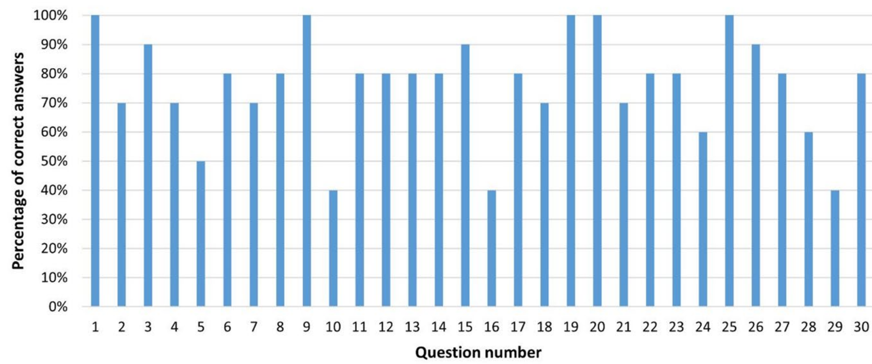

Fig. 7 Percentage of correct answers for each question in the third self-assessment test

continued instructional support for a subset of students, while confirming that the majority are progressing well along the educational pathway.

4.5 Progressive learning gains across the three training tests

To assess knowledge progression across the training program, we compared results from the three self-assessment tests administered in each e-learning phase (see Sect. 3.2). The following analysis illustrates trends in performance, learning gains, and reduction of variability over time.

The progression observed across the three training tests reveals a consistent improvement in students' geospatial knowledge and competences.

In the first test, scores ranged from 5 to 29, with a mean of 19, a median of 20, and a standard deviation of 7. The wide distribution and several low scores indicate initial difficulties, likely stemming from heterogeneous academic backgrounds and limited prior exposure to GIS and remote sensing.

In the second test, scores narrowed to 10–32, with a higher mean (23), median (25), and a slightly higher standard deviation (8). More than half of students scored above 24. These changes reflect a marked improvement in overall performance. The more concentrated distribution suggests growing engagement and a better grasp of the topics introduced during the in-person training phase.

The third test confirmed the trend: scores again ranged 10–30, with a mean of 23, a median of 27 and standard deviation further reduced to 7. Scores were more clustered in the upper range, showing consolidated understanding following the mentored application phase.

Overall, the progressive increase in scores, coupled with the reduction in variability, demonstrates the effectiveness of the modular educational approach. Students progressed from a wide range of performance in the first test to more homogeneous and higher-level outcomes in the third, indicating not only knowledge acquisition but also readiness for more advanced applications and potential fieldwork in geospatial analysis.

4.6 Overall student satisfaction and feedback on the full training program

As outlined in Sect. 3.5, we administered a final satisfaction questionnaire to evaluate the overall effectiveness, inclusivity, and impact of the training program. The results below include both quantitative and qualitative insights, as well as statistical tests linking satisfaction to demographic and participation variables.

The final evaluation questionnaire (Table S1) was completed by students all under the age of 30, with most under 24 (63%, Fig. 8). Although this age restriction was not planned by the organizers, it emerged naturally from the respondents' profiles. It is plausible that younger students (still engaged in university studies) were more motivated to provide feedback on the training. Among respondents, 69% were male and 31% female, indicating a good level of gender inclusivity (Fig. 8).

Most students (63%) participated in all three phases of the training program. The average overall satisfaction rating assigned to the full training path (e-learning, in-person, and mentored activities) was 3.8 out of 5, reflecting a generally positive perception.

Interestingly, 63% of respondents reported this was their first experience in an international cooperation project, highlighting how the initiative successfully reached populations typically underserved in science and technology education.

The questionnaire included both multiple-choice and open-ended questions. Respondents were invited to answer open questions in either English or Urdu; all chose English, and their responses were fully comprehensible.

In open question 5, students who did not attend all three phases most frequently cited time constraints. They tended to prioritize in-person sessions and the mentored practical work (phases 2 and 3, i.e. in-person lectures during the two training courses offered in May and August 2023, and semi-autonomous work activities with remote tutoring), while still appreciating the e-learning module (phase 1).

In open-ended questions 17 and 20, students expressed high levels of satisfaction and reported that the training had improved their knowledge and skills. Some students mentioned having applied these skills in real-life contexts, for example, in work with local authorities on mapping glacial lakes at risk of GLOFs. Others requested future training modules focused on drone photogrammetry and topographic product generation.

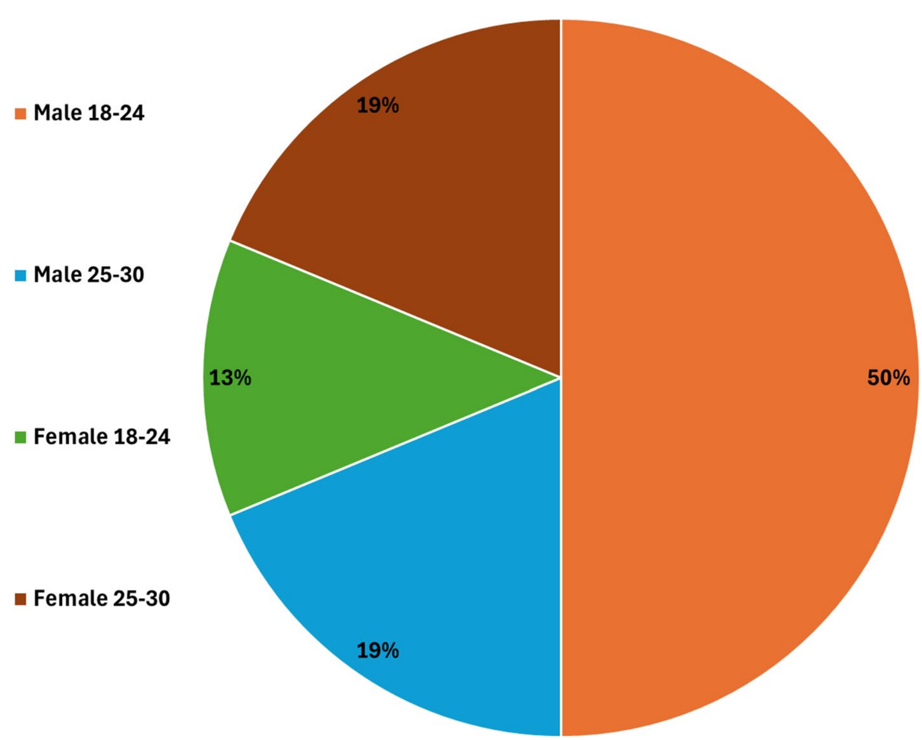

Fig. 8 Pie chart showing student age distribution by gender

A specific question investigated whether students appreciated the presence of a Pakistani-origin instructor. Responses indicated strong appreciation for the cultural proximity and the inspirational value of his academic journey. The trainer, a PhD student in Italy at the time, served as a positive example of international career development in environmental sciences.

When asked whether they would like to stay in touch with the project team, over 90% said yes. Notably, 31% were interested in job opportunities in Pakistan, while 66% hoped to receive training and career opportunities abroad.

To assess the effectiveness and inclusivity of the Glaciers & Students educational program, we conducted a series of statistical tests (Table 4) on the final questionnaire responses ($n = 64$). The analysis focused on satisfaction levels and their relationship with demographic variables, participation patterns, prior experience, and teacher preferences.

Statistical analysis of the final questionnaire responses ($n = 64$) revealed no significant differences in satisfaction levels across gender ($\chi^2 = 5.75$, $p = 0.124$, Cramer's V = 0.300) or age groups ($r = 0.013$, $p = 0.918$, 95% CI [0.000, 0.057]). These findings suggest that the educational model was perceived positively across demographic categories. Students who participated only in the first phase reported significantly lower satisfaction (t = −5.72, $p < 0.001$, Cohen's d = 4.07), indicating a very large effect size. Those who used the acquired skills showed higher satisfaction (t = −2.74, $p = 0.008$, Cohen's d = −0.637), reflecting a moderate effect of practical application. Although the difference between full and partial participation was not statistically significant (t = 0.69, $p = 0.496$, Cohen's d = 0.182), the small effect size suggests a mild trend toward higher satisfaction among fully engaged students. For teacher preference, the chi-square test was significant ($\chi^2 = 34.38$, $p < 0.001$), but Cramer's V could not be computed due to low variability in the contingency table.

To complement the statistical evaluation, we calculated a composite satisfaction index for each participant using a normalized 0–100 scale. The index integrates the final satisfaction rating (1–5 stars) with binary responses to five key questions about the training experience. Each component was normalized to ensure comparability across participants.

The calculated average composite score was 87.55, with a standard deviation of 14.29, ranging from 45.00 to 100.00. These values indicate a generally high level of satisfaction, with higher scores associated with full participation and positive feedback. A weak positive correlation with age ($r = 0.19$) suggests slightly higher satisfaction among older students. The index provides a synthetic metric to assess perceived quality across different phases of the project and supports future comparisons and monitoring of educational

Table 4 Summary of statistical tests

Test	Statistic	*p*-value	Effet size	95% Confidence Interval
Chi-square: Gender vs. Satisfaction	$\chi^2 = 5.75$	$p = 0.124$	Cramer's V = 0.300	-
Correlation: Age vs. Satisfaction	$r = 0.013$	$p = 0.918$	-	[0.000, 0.057]
T-test: Full vs. Partial Participation	t = 0.69	$p = 0.496$	Cohen's d = 0.182	-
T-test: Used Skills vs. Not Used	t = −2.74	$p = 0.008$	Cohen's d = −0.637	-
T-test: Only First Phase vs. Others	t = −5.72	$p = 0.000$	Cohen's d = 4.07	
T-test: Prior Experience vs. No Experience	t = −2.48	$p = 0.016$	Cohen's d = −0.63	
Chi-square: Teacher Preference vs. Satisfaction	$\chi^2 = 34.38$	$p = 0.000$	Cramer's V = n/a	

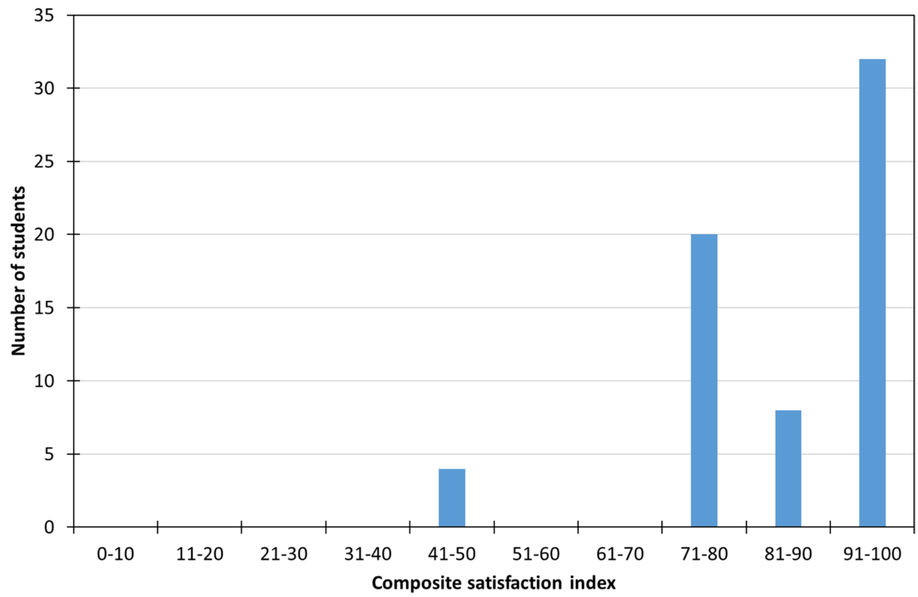

Fig. 9 Distribution of the composite satisfaction index from the final questionnaire

impact in similar cooperation initiatives. This approach strengthens the evaluation framework by combining subjective and objective indicators.

Figure 9 illustrates the distribution of the composite satisfaction index across participants. Most students scored in the upper range of the scale, confirming the overall positive perception of the training program. The relatively narrow spread of values suggests a consistent appreciation of the multi-phase structure, particularly among those who completed all stages of the program.

Taken together, the results demonstrate a progressive acquisition of geospatial skills through the project's multi-phase structure, culminating in high levels of student satisfaction and application of acquired knowledge. These outcomes offer initial evidence of the effectiveness of the blended learning model in strengthening geospatial capacity in LMIC contexts.

5 Discussion

Our findings are discussed in this section in light of the existing literature on capacity building and geospatial education in LMICs, to assess the extent to which the Glaciers & Students model addressed the identified gaps.

Recent literature offers substantial evidence that GIS-based learning, when embedded within sound pedagogical frameworks, fosters the development of key competences such as geographic knowledge, spatial thinking, inquiry-based reasoning, and problem-solving skills [38–40]. Despite these benefits, the integration of GIS into educational settings remains uneven and often superficial [41]. This disparity is largely attributed to persistent challenges including limited teacher training, insufficient technical support, and the marginal positioning of geospatial content within formal curricula [42, 43]. In recent years, however, the rapid expansion of web-based platforms, open-source geospatial tools, and mobile applications has significantly improved access to GIS technologies [10] These innovations have enabled more student-centered, data-driven, and inquiry-oriented learning experiences, particularly in resource-constrained environments [41].

In open-ended responses, students frequently used the term 'real world' to describe the applied and job-relevant nature of the activities, particularly the opportunity to engage in tasks resembling those found in professional or institutional settings. This included processing satellite images, interpreting glaciological data, and collaborating in international teams, skills perceived as directly transferable to employment in the environmental sector.

When interpreted through the lens of Kirkpatrick's Four-Level Model, the observed data suggest that the training was successful in terms of participant engagement (Level 1), learning outcomes (Level 2), and behavioral application (Level 3). While long-term results (Level 4) were beyond the scope of this study, anecdotal feedback indicates that several participants applied acquired skills in professional contexts.

Our exploratory statistical analysis provided empirical support for the training model's effectiveness. It demonstrates that structured, multi-phase training can lead to measurable improvements in student satisfaction and perceived skill acquisition. While the sample size was sufficient for basic statistical testing, future studies should consider longitudinal tracking and standardized pre/post assessments to validate learning outcomes more rigorously. The observed trends align with findings from Bernhäuserová et al. [44] and Favier et al. [40], who emphasize the importance of continuity and contextualization in geospatial education. To our knowledge, this is among the first international cooperation projects in geoscience education to implement a structured and multi-dimensional evaluation framework, encompassing cognitive, affective, and behavioral learning outcomes. This methodological innovation strengthens the replicability of the model and its relevance for future educational initiatives in climate-vulnerable regions.

Furthermore, emerging research has begun to critically examine the epistemological and ethical dimensions of GIS, including issues of representation, power asymmetries, and data governance [45]. This has opened up new directions for leveraging geospatial tools in support of education for sustainable development, with a focus on both environmental literacy and civic engagement [46, 47]. The "Glaciers & Students" initiative offers a valuable case study of international technical cooperation in geoscience education, particularly within low- and middle-income countries (LMICs), where limited data accessibility, weak institutional coordination, and financial constraints often hamper effective climate action and the implementation of long-term environmental monitoring systems [48]. While many educational interventions focus on the transfer of technical skills, few incorporate a structured multi-phase format (i.e. combining e-learning, in-person fieldwork, and remote mentoring) and even fewer include an evaluation framework. Our findings contribute to the broader literature on geoscience capacity building in climate-vulnerable regions, highlighting the importance of context-sensitive training models that are both inclusive and operationally sustainable.

Compared to traditional short-term training formats, the three-phase model adopted here appears more effective in reinforcing long-term learning, professional motivation, and applied skills in remote sensing and GIS. These results align with prior studies emphasizing the need for continuity, mentoring, and localization in international educational programs (e.g [44]). While promising, this model is not without limitations. Challenges such as uneven internet access, language diversity, and logistical constraints must be addressed in future iterations. Moreover, further research is needed to validate the observed learning outcomes with standardized pre/post-testing and longitudinal tracking of career impacts. In addition, some methodological limitations should be acknowledged for transparency. First, participation in all phases of the project was voluntary, introducing a potential self-selection bias, as more motivated or digitally skilled students may have been more likely to enroll and persist through the training. Second, dropout effects occurred across the phases, with fewer students completing the remote mentoring phase than the initial e-learning module (i.e. an expected but relevant pattern in long-term educational programs in LMIC contexts). Third, the questionnaires used to assess knowledge and satisfaction were adapted rather than formally validated, raising the possibility of response bias (e.g., overly positive feedback due to enthusiasm or perceived expectations). Despite these limitations, the mixed-methods evaluation, combining quantitative test results and qualitative feedback, provides a consistent picture of progressive learning and engagement. Future studies should aim to reduce these biases through more systematic sampling, independent validation of evaluation tools, and longitudinal monitoring of participants' career trajectories. Nevertheless, this case study provides a replicable and adaptable framework for international geoscience education, and demonstrates how investment in human capital (when aligned with global agendas) can foster scientific cooperation, local empowerment, and environmental sustainability.

The relevance of this project extends beyond pedagogy. Glaciers are critical water sources in South Asia [49, 50], and improved capacity for glacier monitoring has direct implications for climate adaptation, risk prevention, and water resource management in transboundary basins [51]. In this regard, the creation of a national glacier inventory by trained students illustrates how education can support not only individual advancement but also strategic environmental governance.

In addition, as reported by Boggs et al. [52], components of the geosciences directly or indirectly address all 17 UN Sustainable Development Goals, and geoscientific knowledge is essential in efforts to address climate change. In particular, our project contributes to SDG 4 (Quality Education), through access to inclusive, high-quality training, SDG 5 (Gender Equality), via targeted efforts to increase female participation, SDG 6 (Clean Water and Sanitation), by enhancing monitoring of water-related ecosystems, SDG 13 (Climate Action), through improved local capacity for climate data analysis, and SDG 17 (Partnerships for the Goals), via sustained collaboration between institutions from the Global North and South.

6 Conclusions

The "Glaciers & Students" project demonstrates that a structured, multi-phase educational model (combining e-learning, in-person training, and remote mentoring) can effectively foster geospatial competences in low-resource contexts. Beyond enhancing technical skills in GIS and remote sensing, the initiative also nurtured students' professional aspirations and enabled meaningful cross-cultural collaboration. Moreover, the study confirms that a multi-phase, mentored training approach can offer a viable alternative to short-term workshops or isolated e-learning modules, by promoting continuity, engagement, and real-world application, three elements identified as critical gaps in the literature and in existing cooperation practices.

Participation numbers varied across the different phases of the program. While 90 students were initially involved in the theoretical training (thanks to the long-standing institutional network of the NGO Ev-K2-CNR in Pakistan) approximately 60 students actively participated in the subsequent practical and remote mentoring activities. This variability was not accidental but reflected a conscious decision to offer flexible participation, allowing students to engage when and how they could. This approach proved particularly important in a developing country context, where infrastructure, personal obligations, or limited connectivity can pose significant barriers to continued participation. Offering this flexibility helped foster inclusive growth and extended educational opportunities to a wider audience.

Quantitative evaluation through self-assessment tests and final surveys revealed a clear progression in learning outcomes. Quantitative analyses supported these findings: significant differences in satisfaction were observed between students who completed all phases and those who only attended the first one (very large effect size), while practical application of skills was associated with higher satisfaction. The exploratory composite satisfaction index confirmed generally positive evaluations across participants, reinforcing the effectiveness and inclusivity of the proposed educational model.

It is also important to reiterate that the glacier inventory produced through this project is not intended as a validated scientific product. Rather, it functioned as a pedagogical instrument to consolidate students' technical learning. A separate peer-reviewed publication will present its validation and scientific comparison.

Although the feedback and test results from Italian students were not included in the present study, their involvement was essential in fostering intercultural exchange and peer-to-peer learning. Future studies may explore comparative analyses to evaluate the cross-cultural impacts of joint geoscience training initiatives which could provide further insights into the mutual benefits of international cooperation in higher education.

To our knowledge, this is one of the first international cooperation projects in geoscience education to implement a structured and multi-dimensional evaluation framework, integrating cognitive, affective, and behavioral indicators. The project thus contributes not only to the pedagogical literature but also to the operational toolkit for development cooperation.

Its design aligns with contemporary educational theories and with principles of effective cooperation, offering a replicable model for future initiatives in science education. Moreover, its contribution to several Sustainable Development Goals (particularly SDG 4-Quality Education, SDG 5-Gender Equality, SDG 6-Clean Water and Sanitation, SDG 13-Climate Action, and SDG 17-Partnerships for the Goals) highlights the strategic value of investing in human capital through context-sensitive training initiatives.

Looking ahead, future iterations should address digital access barriers, integrate long-term tracking of career trajectories, and explore the application of emerging technologies such as artificial intelligence in geospatial analysis. In doing so, similar programs can further enhance their impact and sustainability, strengthening both individual empowerment and institutional capacity in climate-vulnerable regions.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s44288-026-00414-8.

Supplementary Material 1.

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Author contributions
D.F., A.S., R.U.H., M.A.Z., S.M., A.H., M.T.M. and G.A.D. conceived the study; D.F., A.S., A.A., B.B., M.C. F.D.,M.T.M. and G.A.D. performed project activities, D.F., A.S., A.A., M.T.M. and G.A.D. wrote the paper.

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Data availability
The authors declare that the data supporting the findings of this study are available within the paper.

Declarations

Ethics approval and consent to participate
This study did not require approval from an ethics committee, as it involved an anonymous, voluntary questionnaire conducted for educational research purposes, with no collection of sensitive or identifiable personal data. According to Italian and European regulations, this type of research is exempt from formal ethics committee review, in particular Regulation (EU) 2016/679 (GDPR) and Italian Legislative Decree No. 196/2003, as amended by Legislative Decree No. 101/2018. Participants were informed about the purpose of the study, the anonymous nature of data collection, and the use of data exclusively in aggregated form for scientific research. Informed consent was obtained implicitly through voluntary completion of the questionnaire. Participants were informed about the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any time. No participants under the age of 18 were involved in the data collection or educational activities described. All participants voluntarily agreed to take part in the educational activities and surveys associated with the "Glaciers & Students" project, after being informed about the aims and procedures of the study. Informed consent was collected from all participants involved in the study prior to participation.

Consent for publication
All participants provided informed consent for the publication of non-identifying data and photographic material in this open-access article. No identifying personal information is presented. The individuals depicted in the included photograph explicitly agreed to its publication for educational and research dissemination purposes. Informed consent for publication was obtained from all participants. No participants under the age of 18 were involved.

Competing interests
The authors declare no competing interests.

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