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Guglielmina DIOLAIUTI [1], Maurizio MAUGERI [1], Antonella SENESE [1*], Michela PANIZZA [1], Roberto AMBROSINI [1], Gentile Francesco FICETOLA [1], Marco PAROLINI [1], Davide FUGAZZA [1], Giacomo TRAVERSA [1,2], Daniela SCACCIA [3], Massimiliano FRANCESCHINI [3], Luca CITRON [3] & Manuela PELFINI [4]

IMMERSIVE AND VIRTUAL TOOLS TO SEE AND UNDERSTAND CLIMATE CHANGE IMPACTS ON GLACIERS: A NEW CHALLENGE FOR SCIENTIFIC DISSEMINATION AND INCLUSIVE EDUCATION

Abstract: Diolaiuti G., Maugeri M., Senese A., Panizza M., Ambrosini R., Ficetola G.F., Parolini M., Fugazza D., Traversa G., Scaccia D., Franceschini M., Citron L. & Pelfini M., *Immersive and virtual tools to see and understand climate change impacts on glaciers: a new challenge for scientific dissemination and inclusive education.* (IT ISSN 0391-9838, 2021).

Dissemination and communication of landscape features have been for long time an important goal for explorers and travellers. The description of landforms and of the processes that determine them now assume a key role in geoeducation. From this point of view, outdoor experiences represent a great opportunity to improve the scientific knowledge of students. However, field work and field experience can be limited by both external and internal causes. For instance, organizational, economic, pandemic and personal issues can reduce the opportunities to take advantage of outdoor experiences, especially for the most fragile students such as those with disabilities. These problems are even bigger when environments difficult to reach are concerned, like glaciers.

For this reason, after a brief historical background on the techniques used to describe landscapes and the related processes, we propose an innovative application of virtual tools for education and outreach activities: an immersive experience to visit an alpine glacier by means of 360° contents. The chosen area is the Forni Glacier (Stelvio National Park, Italy). The high resolution of videos and pictures from the proposed virtual visit brings the investigated area really close to viewers and it conveys the illusion of a real field trip. In order to increase the fruition of this innovative experience, we make the multimedia products usable everywhere via smartphone or tablet or by means of VR (Virtual Reality) headsets. We present also the results from some tests to evaluate the educational and disseminative efficacy on different targets.

Key words: Alpine glaciers, Climate change impacts, Virtual experience, Immersive vision-reality, Geoeducation.

Riassunto: Diolaiuti G., Maugeri M., Senese A., Panizza M., Ambrosini R., Ficetola G.F., Parolini M., Fugazza D., Traversa G., Scaccia D., Franceschini M., Citron L. & Pelfini M., *Strumenti immersivi e virtuali per poter osservare e comprendere gli effetti del cambiamento climatico sui ghiacciai: una nuova sfida per la divulgazione scientifica e la didattica inclusiva.* (IT ISSN 0391-9838, 2021).

Uno degli obiettivi di esploratori e viaggiatori del passato era quello di comunicare e diffondere le evidenze paesaggistiche. La descrizione delle forme del paesaggio e dei processi che le regolano diventa particolarmente importante nella comunicazione delle Scienze della Terra. In questo senso le esperienze in campo rappresentano una grande opportunità per incrementare le conoscenze scientifiche degli studenti. Attività ed esperienze sul terreno possono tuttavia subire limitazioni per l'intervento di fattori esterni e cause interne. Problemi organizzativi, economici, pandemici e personali sono alcuni dei fattori che possono ridurre le opportunità per gli studenti di trarre vantaggio da tali esperienze, in particolare quelli più fragili come i disabili. Queste problematiche sono ancora più marcate se si fa riferimento agli ambienti più difficili da raggiungere quali quelli glaciali.

Per questa ragione, dopo una breve sintesi del percorso storico sulle strategie di comunicazione utilizzate per descrivere i paesaggi e i processi che ne regolano l'evoluzione, viene qui proposta un'applicazione innovativa di strumenti virtuali per la didattica delle geoscienze: un'esperienza immersiva per visitare un ghiacciaio alpino attraverso contenuti a 360°. L'area scelta è quella del Ghiacciaio dei Forni (Parco Nazionale dello Stelvio, Italia). L'alta risoluzione dei video e delle immagini rendono l'area analizzata molto vicina ai visitatori creando l'illusione di un'escursione reale. Al fine di favorire la diffusione dell'esperienza immersiva i prodotti multimediali sono fruibili ovunque attraverso l'uso di smartphone

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o tablet o ancora attraverso dispositivi per la realtà virtuale. Nel presente lavoro vengono presentate inoltre le esperienze realizzate con categorie diverse di studenti e pubblico.

Termini chiave: Ghiacciai Alpini, Effetti del cambiamento climatico, Esperienza virtuale, Visione-realtà immersiva, Didattica delle Scienze della Terra.

INTRODUCTION AND STUDY AIMS

Dissemination and communication of landscape features have represented for a long time an important goal for explorers and travelers (Rüfenacht & *alii*, 2021). This is especially true for glaciers, that are among the most difficult places to reach. Their descriptions have represented an important source of information both for tourists and for scientists in their reconstruction of glacier fluctuations (e.g., Orombelli & Porter, 1982). With the beginning of mountaineering to reach those remote environments like glaciers, mountain literature also started to emerge and today, also on social media platform, descriptions and pictures of glaciers are realized in order to involve common people in the fruition of such spectacular landscapes. Moreover, knowledge about the glacier environment is of great importance in geoeducation, for the crucial role that glaciers have for water storage and availability.

Glaciers are among the most sensitive features of the landscape affected by the ongoing climate changes. Causes and consequences of climate changes are widely discussed both among scientists and common people and a wide literature is available (see IPCC, 2021). A new challenge is to identify and test the most opportune methodologies and technologies to communicate to citizens and students the effects of climate change, especially in remote areas, and to disseminate in a simple and intuitive way the most recent results of scientific research in the field of environmental sciences.

Several scientists are testing new strategies for sharing knowledge and make research outcomes more understandable to the general public, thus increasing consciousness and awareness of students and citizens about climate change and its effects (e.g., Scanlon, 2014; Georgopoulou, 2021; Frigerio & *alii*, 2021). This paper contributes to this topic as it reports the main results obtained in an experiment planned, developed, and performed by the University of Milan to prepare an "immersive experience" (i.e. an inclusive educational tool) to visit the Forni Glacier (Stelvio National Park, Italy, fig. 1), to allow the largest possible number of people (mainly - but not only - students) to visit an alpine glacier and to be virtually part of the scientific team who is studying and surveying it.

The choice to prepare a virtual experience as an educational and disseminative tool instead of a simple documentary was based on the most recent findings in the field of psychology (e.g., Killingsworth & Gilbert, 2010) and on the key concepts of pedagogy and disciplinary education concerning field work and laboratory activities (e.g. Orion, 1993, 2003; Pelfini & *alii*, 2016, 2019).

In this scientific and cultural context, we considered that by proposing experiences to students instead of lessons, seminars, or conferences, we can be more effective in sharing contents and in making them understandable to students. In fact, in a classroom, students are spectators, while if they enjoy an experience, they become protagonists and the result is deeply different in terms of both satisfaction and memorization.

Field and lab educational activities allow students to better understand the natural system and its driving processes, placing them in the correct spatial and temporal perspective. In particular, only by experiencing the glacier environment and visiting a retreating glacier one can deeply understand the impacts of climate change on the cryosphere. In this way, students will easily acquire not only knowledge but also competence and abilities usable also in different contexts. This appears clearly from the results of studies that analysed the impact on students of experiencing geological-geomorphological educational trails and geocultural paths (see Garavaglia & Pelfini, 2011; Bollati & *alii*, 2013; Brandolini & *alii*, 2019; Pelfini & *alii*, 2018, 2020).

Field and lab activities are common in university courses concerning environmental sciences, while in secondary school they are only occasionally planned and offered to students (Sturani & *alii*, 2018). Moreover, in some cases, it is not possible to enjoy a real open-air experience; this is the case for example of people with disabilities and health problems. They cannot enjoy a safe trip on an alpine glacier, or they could do it but with severe limitations and constraints. Recently, the conditions due to the global COVID-19 pandemic have further exacerbated such limitations and require solutions to bring outdoor sites, and in particular mountain glaciers, closer to common people.

In this paper, after a brief historical background on the strategies and methods used to describe landscapes and processes and to disseminate information and knowledge, the virtual experience on the glacier and the related tests to evaluate the educational and disseminative efficacy are presented in order to promote such educational application when fieldwork and fieldtrips are not possible or to accompany traditional educational methodologies.

STUDY AREA

Forni Glacier (10.5 km^2, data from 2016, Paul & *alii*, 2020) is part of the Ortles-Cevedale Group (Central Italian Alps) and has a northerly aspect and an elevation range between about 2600 and 3670 m a.s.l. The Forni valley has been studied since the XIX century, and detailed observations have been carried out by several researchers starting from Omboni & Stoppani (e.g., Omboni, 1861; Stoppani, 1882; Pelfini & Gobbi 2005; Pelfini & *alii*, 2014 and references herein) who contributed to the reconstruction of its glacial history (Pelfini, 1987, 1992). Initially, the attention was mainly focused on the glacier description and on the glacier terminus fluctuations (Desio, 1967), which continue until today (e.g., Santilli & *alii,* 2002, Diolaiuti & Smiraglia, 2010) with the monitoring of the glacier terminus through the glaciological campaigns by the Italian Glaciological Committee (CGI, 1914-1977, 1978-2018; Baroni & *alii*, 2019, 2020a, b) and with investigations of the glacier

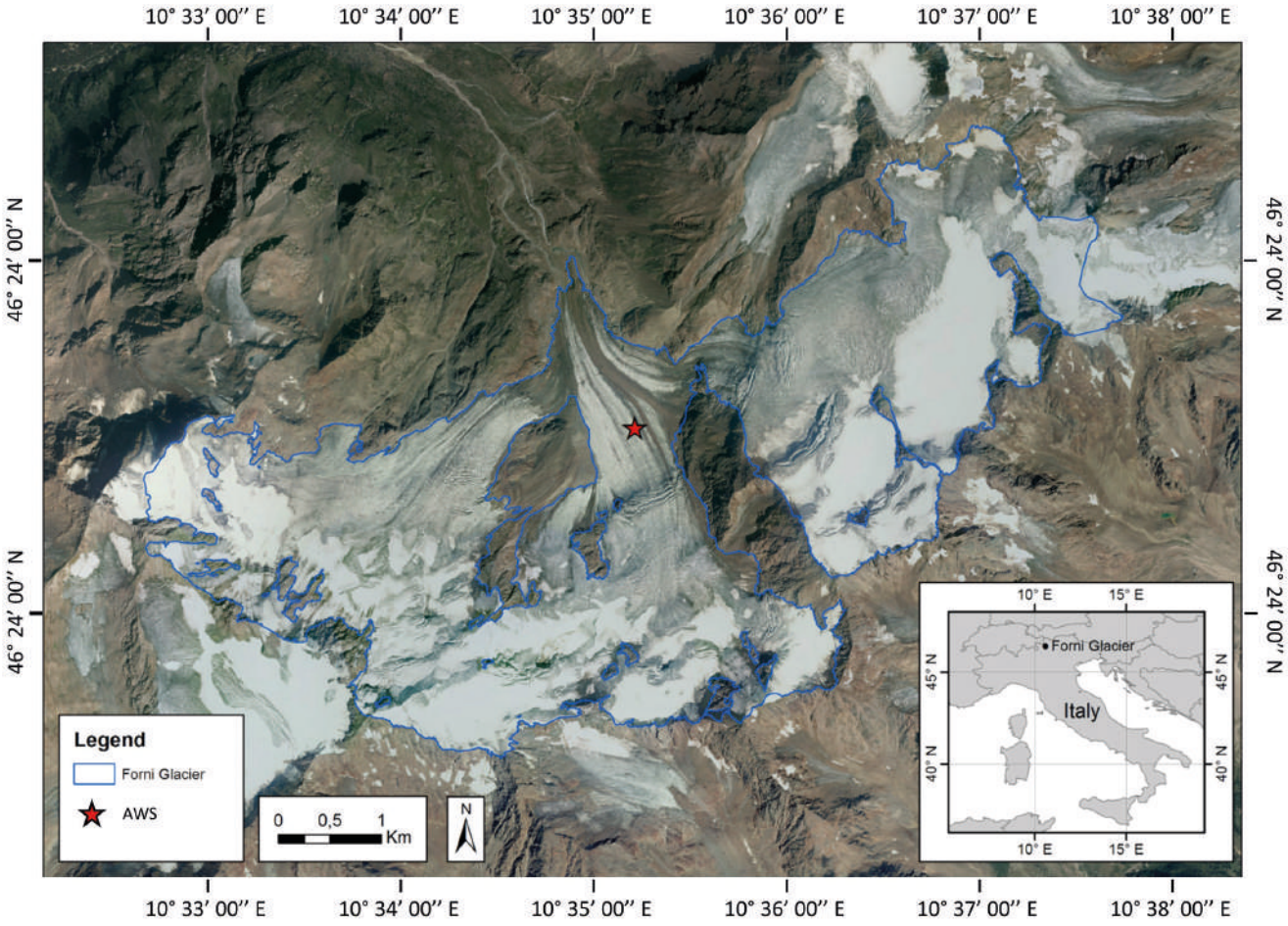

FIG. 1 - The Forni Glacier area. Outlines from 2012 (Azzoni & *alii*, 2018). Background image is the aerial orthophoto from 2012 (https://webgis.provinciasondrio.it/map/?mapset=geoportale).

mass balance (Senese & *alii*, 2012, 2018) and albedo (Azzoni & *alii,* 2016, 2018; Fugazza & *alii*, 2016, 2019). Nevertheless, research progressively focused on different topics including glacier dynamics (Azzoni & *alii*, 2017), advanced remote sensing analyses (Fugazza & *alii*, 2015, 2018, 2021; Senese & *alii*, 2016, 2020), dendrohydrology (Leonelli & *alii*, 2019). Moreover, glacier retreat is accompanied by a progressive widening of the proglacial areas (D'Agata & *alii*, 2020). Here, deglaciation allows observing the beginning of soil development (Egli & *alii*, 2006; D'Amico & *alii*, 2015), biological colonization (e.g., successions of arthropods and other animals, Gobbi & *alii*, 2007; Brambilla & Gobbi, 2014; Zawierucha & *alii*, 2019; Ficetola & *alii*, 2021), bacterial communities (Meola & *alii*, 2014, Franzetti & *alii*, 2020), plants (Cannone & *alii*, 2008; Ficetola & *alii*, 2021) and trees (Garavaglia & *alii*, 2010). Environmental changes are further visible all along the upper Forni valley (Garavaglia & *alii*, 2010) and also along the slopes where the treeline is shifting upwards (Masseroli & *alii*, 2016). On the Forni Glacier, the first Italian supraglacial automatic weather station (AWS1 Forni) was installed in 2005 (red star in fig. 1). The AWS is part of several international networks (e.g., OSCAR - Observing Systems Capability Analysis and Review Tool, SPICE - Solid Precipitation Intercomparison Experiment, and CryoNet, core GCW-Global Cryosphere Watch network of surface measurement stations, all projects developed by WMO - World Meteorological Organization, e.g., Senese & *alii*, 2018). In recent times, Forni Glacier and surrounding areas have also been studied for the climatic inputs in climate change models (Golzio & *alii*, 2018, 2021), the related geoheritage (Pelfini & Gobbi, 2005; Pelfini & *alii*, 2010; Diolaiuti& Smiraglia, 2010) and geotourism (Pelfini & Santilli, 2006), the perception of the effects of climate change (Garavaglia & *alii*, 2012) and the geoeducational importance (Pelfini & *alii*, 2010; Bollati & *alii*, 2015). Moreover, Forni Glacier was the first Alpine glacier where evidence of micro- and macro-plastics contamination was found (Ambrosini & *alii*, 2019; Parolini & *alii*, 2021).

HISTORICAL BACKGROUND ON LANDSCAPE DESCRIPTION TECHNIQUES

The real or metaphor journey has always been a beloved topic in literature, as documented by the iconic example of Odysseus in the epic poem *Odyssey*. Other well-known examples are Dante's otherworldly journey

in *the Divine Commedy, Gulliver's Travels* by Jonathan Swift, and *Around the World in Eighty Days* by Jules Verne. Many other examples could be proposed, as literature is rich of exoticism and discoveries, components that allow the reader to escape from everyday life and grasp the fascination of a different and unknown reality indirectly. Such effect comes from the storytelling of fictitious travels, generated by the author's imagination. To increase people's curiosity, it is necessary to describe the observed world and the landscape in a proper way. In fact, the theme of the description of distant places (such as but not limited to glaciers) has been analysed by many authors of the past. Each of them developed his own descriptive and narrative strategies and methods to take the reader with the mind ("virtually" we would say today) to the described places.

It is on this basis that travel literature was born, even if with different aims: the wish to maintain the memory of a journey by writing a diary, the sharing of emotions with the public, the sharing of practical information, and/or with educational goals. Inevitably, ways and typology of landscape and site descriptions progressively changed over time to accomplish these aims.

The evolution of travel literature started way back in time. The first detailed and true landscape descriptions were already present among the ancient Egyptians who recorded their journeys in painted images on the walls. Similar methods can be found in ancient Greece, where also the first writings were realized, with practical goals such as the administration of territories or simply to improve knowledge of landscape features, especially after the Hellenistic expansion. Since the IV century BC, detailed descriptions of coastal routes can be found; their aim was to list sites and distances among them. Nevertheless, also documents with moderate literary value can be found, for example the work by Pausania (II century AD) named *Description of Greece* was realized with a topographic approach. Even if the main interest concerned monuments and buildings, accurate landscape descriptions were included.

The "experience" represents the driving factor for odeporic (i.e. travel) literature, which started developing in more recent centuries. In the Middle Ages, it is possible to find many texts written with practical aims, developed on the basis of experiences made by two main figures: the merchants and the pilgrims. An example of the latter could be found in the *De itinere Terre Sancte* (1336-1341) by the priest Ludolfo von Sudheim. At the end of his pilgrimage to reach the Holy Land, he wrote what would be now regarded as a tourist guide with two goals: to provide precise instructions to other travellers interested to do the same trip (e.g., reporting much information about costs, distances, transports, dangers, etc…) and to show the trip and the destination to those unable to undertake that pilgrimage. A famous merchant able to claim a direct knowledge of countries and cultures was Marco Polo with *Marvels of the World* (known in Italian as *Il Milione*). In 1271, when the author left, much of central Asia was already known (also thanks to the contribution of travel report authors, such as Giovanni di Pian del Carpine, author of the *Historia Mongolarum*, or Guglielmo from Rubrick, who wrote the *Itinerarium*), but what Marco Polo was telling was really astounding. He observed with insatiable curiosity what surrounded him (e.g., palaces, wealth, clothes, inhabitants, habits) reporting faithful descriptions of that world still unknown to Europe.

However, it is necessary to jump to the XVIII century to see an increase of travel literature production, especially in Italy. Travelling was no longer an exclusive prerogative of the educated class, but it was open to people from all social and cultural backgrounds. In fact, in 1700 travelling became popular. The offsprings of aristocracy were used to go to cities of art for cultural purposes and to complete their education (the so called "Grand Tour"); nevertheless, the middle class started travelling as well. Travel was no longer an exclusive event, but it became a democratic experience. Mass tourism was born (Clerici, 2013). At that time, the travel literature opened up its doors to a growing number of authors. The outcomes were qualitatively different: there were many works with an artistic intent, such as Goethe and Sterne's ones. There were female writers as well, such as Madama du Bocage or Hester Lynch Piozzi, who wrote travel works pleasant to be read (Brilli, 1987). At that time, there were still a lot of people unable to travel: since they were not allowed to enjoy direct experience, they travelled only through other people's eyes, memories and words (Clerici, 2008).

The possibility of travelling increased at the same pace as the public demand for travelling literature: many new titles were published between the XIX and the XX century. There were travel series, new publishing houses were opened, magazines and illustrated books were published, which improved the description of landscapes. The reporter was the main character of the literary modernity: he had to fulfil a task given by the newspaper, to answer the needs of the public and of course, he had to use written words in a smart way (Clerici, 2013). Reporters had to be concise and effective because they had only little space on the newspaper. Furthermore, the journalistic reportage offered to the readers an even clearer and more realistic vision of the places, as it often used photography. A brilliant example of reportage was the Italian one named *La metà del mondo vista da un'automobile: da Pechino a Parigi in sessanta giorni*: a cross-border car trip, in which the vicissitudes of the crew are alternated with landscape descriptions (Clerici, 2013). Vocabulary and syntax were really simple and clear and the rhythm created an important emotional impact. The reporter accompanied the volume with pictures taken by him, which were able to bring places and readers closer.

The introduction of the image created an actual revolution: we must say goodbye to literature and pay attention to the media. More recently, thanks to television, it became possible to concretely show places and landscapes. The new tool was the travel documentary, which can have an educational purpose. This is certainly a further approach to direct experience, because images and sounds are more impressed in the experiential memory.

The quality and the resources needed for the productions of documentaries are varied. Many documentary production societies were born, such as BBC and Nation-

FIG. 2 - The 8-sensor video camera in the foreground and an example of field work in the background.

al Geographic, which were able to take advantage of innovative equipment and large budgets for products with great communicative power. Also in Italy, television shows describe far landscapes and territories (e.g., "Geo&Geo"; "Kilimanjaro"; "Sapiens", etc.). These television programs were aimed at reaching a very wide audience and from all cultural backgrounds. Ways and times of communication changed: fruition was simple and immediate, because people were able to access new knowledge quickly and in a captivating way.

The documentary is a new way of describing the landscape: it is a story made up of images and sounds and words are just a narrative support. In fact, the image creates a strong visual impact, which is effectively imprinted in the memory because of the power of emotional involvement. The brief texts have a simple and linear syntax and the vocabulary is immediately understandable to a wide audience. In fact, it is necessary to be clear and incisive, because the communicative relationship is immediate and it is not possible to re-read passages as it was done when preparing a written work. Even the sound is really important because it interacts with the image and with the viewer who, thanks to the audio, can better understand the message. Last but not least, we must not forget the importance of the ambient audio (i.e. sounds and noises present in a certain place) that helps to bring the viewer closer to the real experience. In addition, the documentary allows the transmission of knowledge, feelings, emotions in a vivid and tangible way, but it is not as powerful as the direct experience, the only one that can be indelibly imprinted in the memory.

This brief path into travel literature shows how it developed over the centuries, moving from a genre to another and using different narrative techniques, and underlines how certainly, in the past, the only possible way to know distant places was by reading travel stories and travel reports of the great explorers. Over time, audiovisual technology has made it possible to acquire photos, videos and audio recordings, which have certainly increased the possibility of knowing the places narrated with other senses, in addition to reading.

What unites the distant past (written travel chronicles) with more recent times (videos, documentaries, etc.) is that in both the reader or the viewer is a spectator and not a protagonist. To overcome this limit, over the past few years, computer strategies have been developed to introduce the viewer into the environment described. These are virtual reality strategies, augmented reality, or immersive experiences.

An "immersive experience" is an experience, which pulls a person into a new or augmented reality, enhancing everyday life (by making it more engaging or satisfying) via technology. Often, one or more technologies are linked together for the purpose.

The transition from spectator to protagonist is crucial. Being protagonist means taking part in the story, being present in the place described, observing what the experts do in the field. This means "experiencing" and not just learning by observing. Experimenting, according to the well-known "hands on" didactic approach, allows memorizing and preserving in one's own experience what is explained and illustrated in the immersive videos, with totally different effects on the quality and speed of learning.

FIG. 3 - The Forni Glacier and its glacier foreland (from Branca Hut, August 2009).

The peculiarity of educational immersive videos is that not only the viewer is the protagonist, but also the teacher (i.e. the specialist who illustrates his own research or explains the site) is the protagonist and addresses the virtual visitor directly, speaking and explaining to him the various phases of the work carried out in the field. The protagonists are therefore two and this is fundamental in the learning process. In a normal documentary or didactic video, the specialist explains to everyone, while during the immersive experience the specialist speaks to the virtual visitor, establishing a relationship with him. From an educational point of view this is a real revolution.

METHODS

In the case of the immersive experience on an Alpine glacier, the researchers and technicians of the University of Milan based this experience on 360° contents. 360° content is a video you can "explore". This is possible thanks to 3DoF (Degrees of Freedom) experiences: standing at a fixed point, the virtual tourers can look in any direction turning their head left or right, tilting it up or down, or pivoting left and right. 360° contents are obtained by means of an 8-sensor video camera (fig. 2) that shoots in all directions of space (360° horizontally and vertically, as it is also possible to view the ground and the sky of the investigated site). The acquisition by the 8 sensors is synchronous and it is added to the acquisition of the ambient audio (so you can hear the noise of the glacier, the water flowing on its surface, the creaking of the ice under the crampons of the researchers, the noise of the wind blowing on the glacier) and the audio of the expert who is speaking to the virtual visitor explaining his research or the glacier system. The audio and video files are post-processed and coupled in the laboratory and this process leads to a 360° immersive product that can be used with special VR (Virtual Reality) headsets.

During summer 2019 we captured several 360° videos on the surface of the Forni Glacier and in its glacier foreland (fig. 3), during the scientific activities performed by researchers from the University of Milan (e.g., sampling glaciers and meltwater, measuring ice ablation, downloading data from the supraglacial automatic weather station).

FIG. 4 - An example of the virtual experience on the Forni Glacier available at the link https://video.unimi.it/video/forni_glacier_360/ or using the QR code.

RESULTS

Considering the great importance of Forni Glacier as open-air laboratory, we decided to develop here an innovative method to visit the glacier and the surrounding areas and to see and understand the consequences of climate change on Alpine environments.

360° videos of Forni Glacier have been filmed following the most recent indications for teaching through audio-video means that recommend proposing experiences or films that are a few minutes long to maximize their effect in consideration of the average attention time. For this reason, all videos have a duration of less than 5 minutes to prevent boredom or distraction from limiting the effectiveness of the experience.

Researchers always address the virtual visitor directly, involving him in the work carried out or in the explanation provided also through questions. 360° videos were initially shot in Italian only, as the intended use was for students of the University of Milan or Italian citizens interested in popular scientific topics. Afterwards, the presence of international degree courses at the University of Milan and, consequently, of an international audience suggested subtitling the videos in English, to make them usable to non-native Italian virtual viewers.

The English 360° videos are: i) Glaciers are witnesses. They are the best evidence of Climate Change; ii) Short, black and full of holes! How is the glacier tongue changing; iii) The plastic-made glacier. A unique case or a common situation? iv) Not only harmful: bacteria also have positive features! The most recent microbiological research on Alpine glaciers; v) White and red snow! How the UNIMI glacier AWS helps describe snow accumulation on glaciers.

The 360° videos were designed to be used firstly through VR headsets such as Oculus Go; these are commercial viewers commonly used to enjoy video games or immersive play experiences. After putting on the VR headset, the virtual visitor just needs to turn around moving the head to explore the virtual space without the limits commonly imposed by the screens or the space shot. A further advantage of these devices is that the virtual visitor is really immersed in the experience and is therefore isolated for a few minutes from external reality and therefore from distractions or interferences that commonly occur in the case of flat videos or traditional documentaries.

In order to increase the fruition of this innovative experience, we decided to modify the multimedia product, to make it usable also via smartphone or tablet. The web site that contains the immersive experiences subtitled in English can be reached without the need of specific apps at the link https://video.unimi.it/video/forni_glacier_360/ or using a QR code (see fig. 4). Once on the website, the

viewers can choose which visits to experience and use their device to navigate the entire space of the visit. Navigation is still at 360°, the only limit is the lack of isolation from the outside world that was guaranteed by the VR headsets and external noise and interference can disturb the virtual experience in some cases. This can be overcome by using padded headphones.

The advantage of this technology is that the virtual tour can be experienced everywhere (e.g. at home or in a hospital) and not in a specifically suited room (e.g. classroom, museum).

DISCUSSION

These 360° videos were proposed to students and citizens who took part in the European researchers' night (or "Meet me Tonight") which was held in Milan in the "Indro Montanelli" Gardens on 27th and 28th September 2019. For this event, every year the main universities of Milan select a dozen educational-dissemination projects to be proposed to visitors through stands. The stand called "An immersion on the glacier" where we proposed the immersive visit to the Forni glacier was visited by about 1000 people in the 24 hours of opening to the public. Of these, 700 people completed and delivered an anonymous questionnaire to evaluate public satisfaction with the didactic proposal made. All of the 700 questionnaires delivered reported a very positive opinion for the immersive experience and revealed that many virtual visitors learned for the first time notions on the magnitude and rate of the impacts of climate change on glaciers and on the presence of microplastics and pollutants on their surface.

Subsequently, the immersive visit to the glacier was offered to about a hundred citizens who attended an educational conference held at the "Civic house of water" in Milan and, on this second occasion, the proposal was also welcomed favourably.

Finally, in January 2020 the vision of the 360° videos was proposed to a representative sample of students of the Bachelor degree course in Natural Sciences (L32 according to the Italian code). More precisely, as part of the Physical Geography module, first-year students were offered to experience the virtual visit to the Forni Glacier during class hours using the available VR headsets (12 devices). The proposal was offered after the topics of glaciers and cryosphere were taught through regular frontal lessons (i.e.: through an oral presentation based on power point slides commented by the physical geography professor).

Over 150 students joined the proposal and experienced the immersive view. All students also answered an anonymous questionnaire to evaluate their satisfaction with the proposal and its teaching effectiveness. All the students liked the proposal and 60% also admitted that thanks to the virtual visit they learned information on the glaciers, their evolution and their dynamics that they had not fully grasped through the frontal didactic lessons. Students with Specific Learning Disorders (SLD) and those recognized as having Specific Learning Needs (SLN) also welcomed the proposal with enthusiasm. This could mean that the immersive method is able to deliver content and information bypassing the limits of attention and learning encountered by SLD and SLN students. This latter result is very relevant considering that SLD and SLN students together represent on average 10% of the students enrolled.

The experiments with the VR headsets had a sudden stop with the end of February 2020 due to the global COVID-19 pandemic, which made these devices unusable at community and collective level as possible vectors of the virus. For this reason, after a first moment of reflection and discussion, we decided to modify the multimedia product making it usable also via smartphone or tablet, which are personal devices and thus cannot spread the virus.

Moreover, the possibility of experiencing the virtual visit via personal devices was crucial in 2020 to allow excursions on the glaciers, albeit virtual, to students otherwise unable to go to the field due to the lock-down and the restrictive measures to contain the SARS-CoV-2 virus. In particular, we proposed this experience to students of Bachelor and Master degree courses and of an international master (all offered by the University of Milan) on climate change and its environmental and socio-economic impacts allowing them to experience the visit to the glacier from their PC. Finally, the 360° videos of Forni Glacier were also offered at the Italian Pavilion of EXPO Dubai 2021 and at the 2021 International Science Festival organized by La Sorbonne University of Paris by framing the QR code with always positive feedbacks.

These two international events constituted two further precious tests to evaluate the educational and disseminative efficacy of the product for a vast and heterogeneous public.

CONCLUSION

The immersive vision created through 360° videos in open spaces represents a 'bridge' between concepts and reality, and is a precious tool, allowing to reach as many people as possible, especially those with disabilities or under restrictive measures to contain the pandemic.

In the specific case of cryospheric sciences, where the environment is rapidly changing as a result of climate change, these experiences can help awaken consciences and call each of us to environmental responsibility.

The new proposed product available through smartphones and tablets also revealed other educational potentials. For example, it is possible to ask students to explore the virtual space and to correctly identify and label some elements of the visible landscape (the glacier front, the lateral and frontal moraines, the glacial discharge stream, ice-contact and supraglacial lakes, etc.). It is a sort of scientific treasure hunt that allows students to verify their understanding and knowledge and their ability to recognize the elements of the glacial morphoclimatic system. This is obviously only the first of the products deriving from immersive experiences and we are currently working on other developments for the academic audience and for the wider public of citizens and enthusiasts of high mountain environments.

However, it is clear that virtual visits can never completely replace field work, fieldtrips and real educational visits, which are certainly necessary to acquire fundamental knowledge and skills in many study areas (e.g. Earth sciences, natural sciences and environmental sciences).

Nevertheless, having a series of immersive experiences for the main morpho-climatic systems can represent a valuable tool for physical geography and geomorphology to complement the normal frontal lessons, to better learn aspects and themes difficultly noticeable without direct experimentation. Furthermore, immersive vision does not exclude other teaching approaches currently in use in secondary school such as the Inquiry Based Science Learning method (IBSE, based on problem solving). A further approach that can be associated with immersive vision is that of the Flipped Classroom (FC), which involves several inversions: i) the phase of use of contents is moved mainly outside the classroom (therefore it is more easily applicable in the laboratory and with small groups), taking advantage of the new communication channels and the increasing availability of resources (e.g., texts, audiovisual and multimedia products); ii) in the classroom, the discussion of the information collected, the consolidation and internalization of the correct contents through activities coordinated by the teacher (Garavaglia, 2006) are then carried out. Technologies make it possible to use digital platforms to manage HR and to create inverted lessons. In this case, the 360° immersive visits could refer to the outdoor phase, on the glacier, documenting what has been achieved in the phases independently.

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