Immersive 360° Experiences for Geoscience Learning

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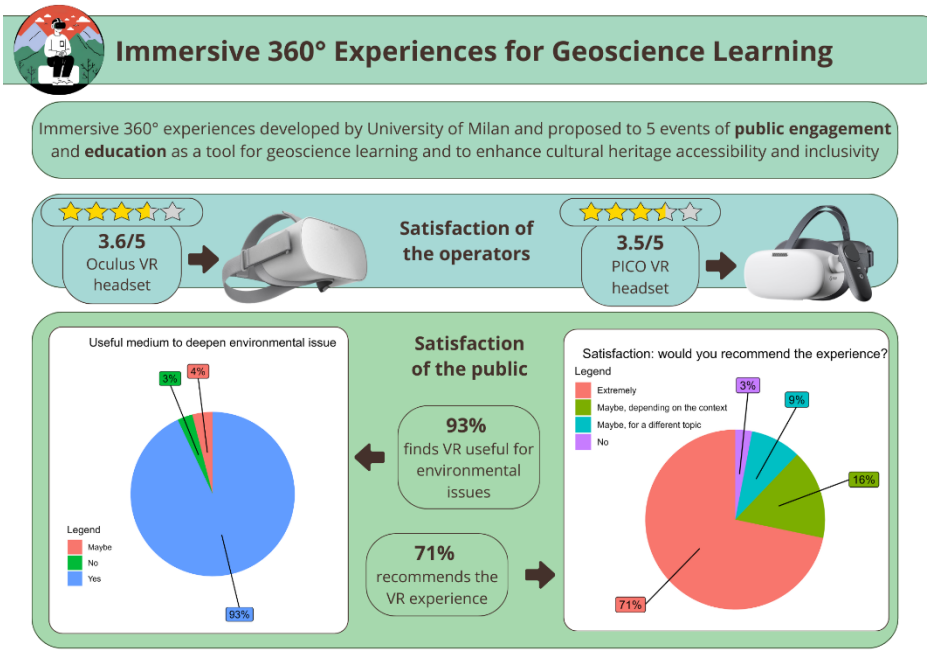

Abstract. Extended reality (XR) and virtual field trips (VFTs) are increasingly used in the field of geoscience dissemination and education as they can enhance the motivation of students and citizens to learn about these topics. They allow to observe the territory and its forms overcoming the possible physical (e.g.

disabilities and health problems), economic, and temporal limitations that are connatural to normal field excursions. Among XR technologies, immersive 360° experiences showing an actual field trip can be even more useful for bringing students and citizens virtually into the considered environment. In this paper, we present the immersive 360° experiences developed by the researchers of the University of Milan (UNIMI, Italy) to support public engagement and education in geosciences, and to enhance cultural heritage accessibility and inclusiveness. In 2023-2024 we proposed these immersive 360° experiences during three public engagement and two education events using Oculus (TM) and Pico (TM) VR headsets to show the impacts of climate change and anthropic activities, and to promote culture and geo-heritage.
Despite some criticalities, we found that this kind of experience can be inclusive for people with a wide range of disabilities and can allow wider access to sites of cultural and environmental interest overcoming social and physical barriers.

Keywords: Immersive Experience, Geo-heritage, Climate Change, Environmental Awareness.

1. Introduction

Extended reality (XR), such as virtual reality and other immersive information and communication technologies (ICTs) have a high potential to transform the way people interact with the real world [1]. Therefore, it is important to investigate their potential implications and influence on how new media and communication technologies can create new cultural messages and approaches [2].

Since one of its first training application in 1966 for the United States air force [3], XR has been increasingly used in the field of geoscience dissemination and education particularly to increase students' motivation [4]. As reported by Diolaiuti et al. [5], XR can be useful for students and citizens to observe the territory and its forms overcoming physical (e.g. disabilities and health problems), economic and temporal limitations that can impair normal field excursions. Following Kippel et al. [6], the challenges involved in a field experience are related to the need to travel to and from the field site. To reduce the costs for participants, very close sites could be chosen, but this reduces the range of possible landscape elements that can be observed and studied. Even if travel costs could be overcome, a site might be inaccessible for many reasons, not only for people with disabilities. For instance, field trip sites can be spatially constrained such as outcrops along highways or at the top of a volcano. On the instructor side, each teacher is often in charge of tens of students or more during field trips, increasing teaching burdens, and inhibiting teacher–student interactions. Weather conditions also influence field trip organization and for this reason they are more frequent in warmer seasons. Finally, in view of carbon neutral scenarios, the carbon footprint associated with travelling should be evaluated [7].

Despite all these limitations, Elkins and Elkins [8] reported significant learning gains in an entirely field-based geology course as well as significant improvements in students' skills compared to standard geology courses and concluded that the more field trip experiences, the better. Based on these findings, proposing as many field activities

as possible is important in geoeducation, but as reported above it is not always possible. To overcome all these limitations imposed by a real field trip, virtual field trips (VFTs) have been used for teaching Earth and Environmental Sciences for decades [9, 10] and desktop-based versions are integrated into online learning environments [6]. In addition to VFTs, immersive 360° experiences in an actual field trip can be even more useful for bringing students virtually into the studied environment. In a previous study [5], we showed that 63% of students indicated that they would enjoy the immersive experiences after traditional lessons of geosciences, but the remaining 37% instead preferred to view these videos before the lessons, maybe because they were able to generate more interest and curiosity and therefore maximize the learning during the traditional lesson.

In this paper, we present the immersive 360° experiences developed by a group of researchers of the University of Milan (UNIMI, Italy) from 2019 to support public engagement, enhance education in geosciences, and increase inclusion.

2. Methods

2.1. The UNIMI immersive 360° experiences

Since 2019 UNIMI researchers have been developing "immersive 360° experiences" that represent inclusive educational and disseminative tools. Spatial immersion in reproduced reality is the perception of being physically present in a non-physical world. This perception is created by surrounding the user of the XR system with images, sounds or other stimuli that provide a highly immersive environment. Spatial immersion occurs when the users feel that the reproduced world is perceptually convincing and have the sensation of being there. To make the experience immersive, the videos were captured by means of an 8-sensor video camera filming in all spatial directions (360° horizontally and vertically, as the ground and sky of the investigated site can also be seen) while also recording environmental audio. First, 15 videos were filmed at the Forni Glacier (Italian Alps) showing the impacts of climate change and anthropic activities [11]. In that occasion, the environmental audio was the flow of water along the glacier surface, the crunching of ice under the crampons, the blowing of the wind. To better highlight the impacts of climate change on a very sensitive landscape element (the glacier), in each video glaciologists, ecologists and climatologists explain and show the effects of human activities on climate and the environment. In this way, during these proposed immersive experiences, students and citizens not only can visit an alpine glacier but they are also virtually part of the scientific team who is studying and surveying the glacier. The researchers always address the virtual visitors directly, involving them in the activities they are carrying out, like sampling ice and meltwater, measuring ice ablation, downloading data from the supraglacial automatic weather station. In fact, Forni Glacier can be considered an open-air laboratory where UNIMI researchers perform a wide range of scientific investigations including glacial history [12], micrometeorology [13], mass balance [14], ongoing surface and volume changes [15, 16], ice thickness measures [17], remote sensing applications [15, 18–20], microplastic contamination assessments [21], ecological studies [22], as well as geoeducational

experiences [11]. In addition, some videos were recorded in the UNIMI laboratories to show the analyses and elaborations of the data acquired both directly in the field and by satellite. In this way, the virtual users can better understand the usefulness of all the field activities seen in the immersive experiences over the glacier. All these videos can be enjoyed with special VR headsets or head-mounted displays (HMD) and are available on the UNIMI webpage as well (https://videolectures.unimi.it:8443/forni_glacier_360/index.htm).

In 2023, the UNIMI was partner of the "E-bike" project supported by the Interreg V-A Italy–Switzerland 2014–2020 Cooperation Program and included in the axis relative to the Enhancement of Natural and Cultural Heritage, with the specific objective of guaranteeing a greater attractiveness of territories characterized by environmental and cultural resources with common features. In the framework of the international project "E-bike" [23], 18 videos were recorded along the "E-bike" cycle path in Lombardy (Northern Italy) for promoting several points of cultural, geological, and naturalistic interest. The sites range from Villa Carlotta (cultural and naturalistic interest, Como Lake, 45° 59' 11.04" N and 9° 13' 51.38" E) to earth pyramids of Postalesio (geomorphological interest, 46° 10' 48.59" N and 9° 46' 21.57" E) to Cancano Lakes (cultural, technological, and naturalistic interest, in Upper Valtellina, 46° 32' 6.58" N and 10° 16' 40.43" E). Villa Carlotta is one of the most representative examples of the combination of cultural and natural heritage. It houses more than three centuries of great art collections, and each year it opens the gates of a fascinating botanical garden that attracts thousands of visitors from all over the world. Thanks to all these videos, users can appreciate the geodiversity and the cultural heritage of Northern Italy. Also in this case, the researchers speak directly to the camera and each video starts with the researcher walking or riding a bicycle to increase the feeling of a dynamic approach by the user. All the E-bike videos can be viewed with special VR headsets or head-mounted displays (HMD) and are available on the project webpage as well (https://ebike-alpexperience.eu/en/treasures-to-discover).

All the 360° videos were shot in Italian, as the first target audience was UNIMI students and Italian citizens. Subsequently, English subtitles were added to the videos shot on the Forni Glacier so that students in UNIMI's international bachelor's and master's degree programs could also enjoy the videos. In a previous survey, we found that subtitles were distracting for the Italian audience. For this reason, the audio of the E-bike videos has been generated in several languages using the TTSMaker open access software (https://ttsmaker.com/) that allows to choose not only the gender of the voice but also the accent. In this way, the videos were available in English and German as well.

We first used Oculus Go 32GB - Standalone Virtual Reality Headset, which have gone out of business in 2023. Then we used PICO G3 - 3DoF All-in-One Enterprise VR Headset with XR2 Chipset and an HD display, longer battery life and a higher refresh rate. Both headsets can be worn even with glasses on.

2.2. The public engagement and educational events

Over the last years, we proposed these immersive 360° experiences in several public events (Fig. 1). The “E-bike” videos were launched at the project's closing event held in October 2023 in Bard (Aosta, Italy) and called “Pedala Forte” (i.e. “pedaling hard”, from the play on words for which 'Forte' is the Italian term for the Bard fortress). In that occasion, the involved public was rather small and mainly made of cyclists and amateur cyclists. Subsequently, we promoted the “E-bike” videos during the "Fà la cosa giusta" (i.e., "Do the right thing”) fair, one of the most important Italian fairs of critical consumption and sustainable lifestyles. Specifically, the purpose of "Fà la cosa giusta" was raising awareness and disseminating good consumption practices for the purpose of a sustainable future. The XX edition was held from March 22nd to 24th 2024 in Milan (Italy). We gave visitors immersive experiences through VR headsets to make them aware that our natural and landscape heritage in Lombardy is sensitive to climate change and to make them conscious on the causes of climate change. A month later, we were involved in the "FuoriSalone" of the Milan Design Week, the leading international event for the design industry (15-21 April 2024) with an open-air lab in front of the Building of Lombardy Region (the building hosting the headquarter of the administrative district where Milan is located, https://www.fuorisalone.it/en/2024/events/3909/LOMBARDY-ON-THE-ROOF-OF-THE-WORLD-FUORISALONE-2024). The Lab was called “Lombardy on the roof of the world” as in the square a pyramid (17 x 17 x 11 m) was located that was then moved to protect the Italian Pyramid Observatory Laboratory located at 5050 m a.s.l. in the Khumbu valley (Nepal) at the foot of the Nepalese side of Everest. This lab represents one of the Italian excellence laboratories for research at high elevations. Also on that occasion, we offered the immersive glacier experience through VR headsets to raise awareness of what a glacier is, and its sensitivity to climate change.

From an educational perspective, we offered the immersive experiences to UNIMI’s students of the Environmental Change and Global Sustainability (ECGS) master's degree program, during the lessons of Geodiversity, and of the Biogeosciences master's degree program, during the lessons of Glaciology.

In addition, UNIMI researchers were partners in the international city-twinning project called "Youth Participation in creating Resilient Cities," an EU-funded program between Turkey and EU-II (Twinning for a Green Future) (TTGS-II). The program is a collaboration between the Italian municipality of Cinisello Balsamo, the Turkish municipality of Edremit and the Legambiente Innovazione Foundation. The theme around which the Town Twinning work was organized was climate change, with a special focus on the role of young people in the necessary ecological transition. In fact, beside the development of a digital and participatory platform that analyzes the links between climate and pollution (curated by the UNIMI), one of the project outcomes was the creation of two Youth Committees for the Environment, in Edremit and Cinisello Balsamo. During one of the workshops, the young people (all attending the Giulio Casiraghi High School of Science) addressed the issue of climate change and the causes that fuel it and, through guided exercises, evaluated the direct consequences that daily actions have on the climate and identified alternatives for reducing their own

environmental impact. To better understand the effects of climate change, the young people also enjoyed the glacier immersive experiences.

Fig. 1. Some photos taken while users were enjoying the immersive experiences with VR headsets at the public engagement events.

2.3. Evaluation of immersive experiences effectiveness

To assess the effectiveness of immersive 360° experiences in Geoscience Learning, we developed specific questionnaires for each event, and a final one to be proposed to the operators (i.e. to the UNIMI staff members involved in the project) after their participation to the events. All the questionnaires were developed with the Microsoft Forms application (educational license Microsoft© and Office 365© provided to all teachers and students by UNIMI).

Satisfaction questionnaire for the public. After the immersive 360° experience, a satisfaction questionnaire was proposed to the participants regarding the instruments and the videos shown. The questionnaire was redacted in two forms due to the different topic of each event. For "Pedala Forte" and "Fà la Cosa Giusta" the questionnaire included 23 questions focusing on cycling experiences (the Italian version is available at https://forms.office.com/e/W10g8k4bgJ), for "FuoriSalone" and "Youth Participation in creating Resilient Cities" it included 19 questions regarding the level of knowledge about glaciers and climate change (the English version is available at https://forms.office.com/e/KGjymg1ppP, the Italian version is available at https://forms.office.com/e/ZPaHMUwQZ8). In the first two events, the questionnaires were given in Italian only because Italian was the main language of the event, and the public was exclusively Italian. In the other events, the questionnaire was both in English and Italian, due to an international public. The questions were multiple answer types and divided into three main sections: (i) general information about the participant; (ii) satisfaction with the immersive experiences; (iii) satisfaction with the topics of the videos and pre-knowledge. The results of the two questionnaires were grouped according to themes to better understand the audience, effectiveness and satisfaction of both events and experiences; separately for each event questions were asked about different aspects of the experience.

Statistical analyses. After collecting the compiled questionnaires, the results regarding both topics were analyzed to find patterns in the answers and to try to identify the most suited audience for these kinds of events and this type of technology. We focused our attention on “Fà la cosa giusta”, “FuoriSalone”, and “Youth Participation in creating Resilient Cities” events for the total number of collected data to obtain a consistent dataset (n. of conducted surveys: 119 during “Fà la cosa giusta” and 335 during “FuoriSalone”, and “Youth Participation in creating Resilient Cities”). We used Pearson’s **c**hi-square tests to investigate the association between the relative frequence of answers to the following questions: i) “occupation” and "interest in environmental topics”; ii) “interest in environmental topics” and “opinion on VR headset as a useful tool to deepen environmental issues”; iii) "occupation” and "opinion on VR headset as a useful tool to deepen environmental issues”. The proportions were represented through a bar plot.

Satisfaction questionnaire for the operators. Another questionnaire with multiple answers was developed and proposed to the operators after their participation to the events (https://forms.office.com/e/sSCAVurB5z). It included 25 questions divided into three main sections: i) general information about the operator, ii) satisfaction with the Oculus devices, and iii) satisfaction with the Pico devices. The questions in the last two sections were conducted using a 5-point Likert scale, a psychometric scale that has multiple categories from which respondents choose to indicate their opinions, attitudes, or feelings about a particular issue [24]. The two VR headsets are evaluated with the obtained final score and their percentage variation computed with the following formula:

$$\%\, variation = \frac{score_{Oculus} - score_{PICO}}{score_{PICO}} \times 100 \quad (1)$$

3. Results

3.1. Satisfaction questionnaire for the public

The satisfaction questionnaire was proposed to the public of “Fà la cosa giusta”, “FuoriSalone”, and “Youth Participation in Creating Resilient Cities” events of education and public engagement. The total number of people interviewed after the events is 454, 119 of which at “Fà la cosa giusta”, and 335 at “FuoriSalone” and “Youth Participation in Creating Resilient Cities”. A part of the interviewees (42%) had previous real-life experiences of the activity proposed in the video and declared themselves as very interested in environmental issues and topics (38%) while another part did not have past experiences with VR headsets (54%) and considered them as a useful medium to deepen environmental issues (93%) (see Fig. 2, A-E).

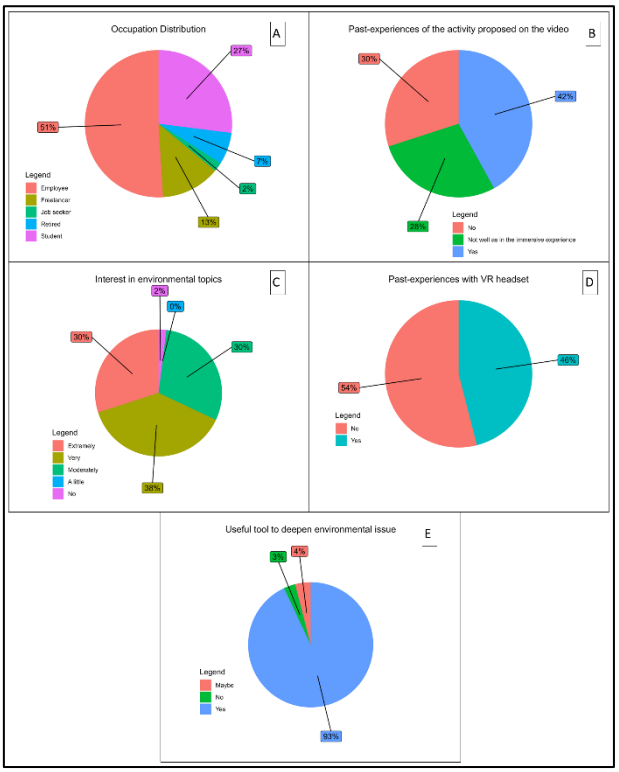

Fig. 2. Results of the questions proposed to all the events after the immersive experience, for a total of 454 interviewees. A: occupation distribution of the interviewees; B: percentage of interviewees which previously had experienced in real life activities proposed in the videos; C: quantification of public interest in environmental issues; D: percentage of interviewees which previously had experiences with VR headset; E: percentage of the public's opinion about VR headset as a tool to deepen environmental topics.

At each event the participants were also asked questions about satisfaction with specific aspects of the experiences and the devices. At the "Fà la cosa giusta" event people were asked to judge the video quality of the Pico headset and if the immersive experiences intrigued the interviewee to do in person what was shown (see Fig. 3, A-B). Results show that 50% of the answers were positive, and the video quality was considered adequate, but 42% considered it improvable. Of the 119 total interviewees, only 4% said they were not interested in doing in person what was shown, instead, the most selected option (40%) was "moderately interested". At the "FuoriSalone" and "Youth Participation in creating Resilient Cities" events three questions were proposed regarding the satisfaction of the interviewees with different aspects of the experience (see Fig. 3, C-E). Most of the participants (71%) answered that they would recommend the experience to others, with only 3% of the 335 interviewees not recommending it. Finally, 93% of the interviewees was satisfied with the presence of the sounds of the

surrounding environment, and 86% was satisfied with the possibility of enjoying the video at 360° instead of having a static screen as in traditional documentaries.

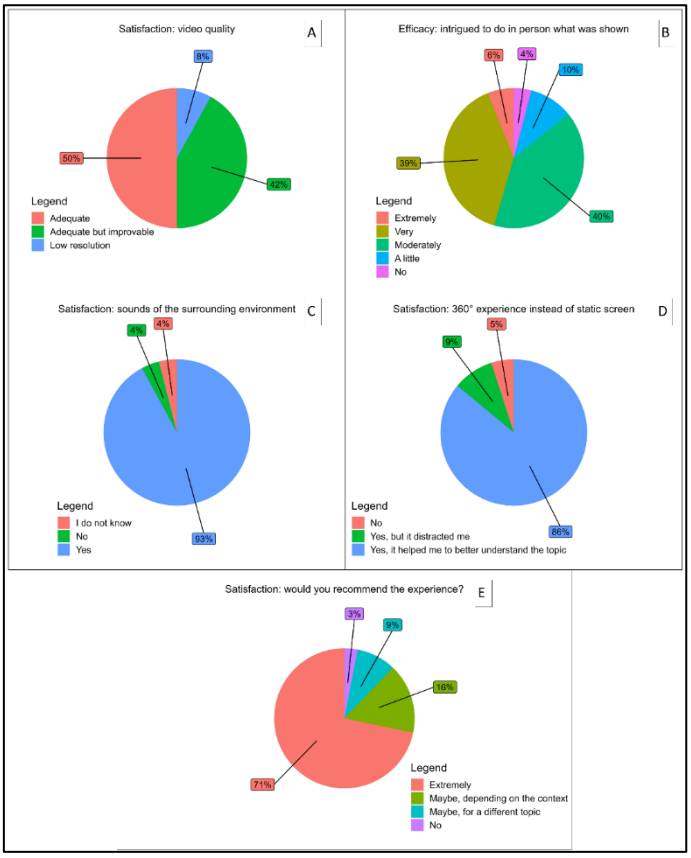

Fig. 3. Results of the questions proposed at each event: A-B to "Fà la cosa giusta" event for a total of 119 interviewees, and C-E to "FuoriSalone" and "Youth Participation in creating Resilient Cities" events for a total of 335. A: level of satisfaction with the video quality of Pico headset; B: level of interest to do in person the activity they enjoyed during the immersive experience; C: level of satisfaction with sound of the surrounding environment during the experience with the Pico headset; D: level of satisfaction with the possibility to explore the surrounding environment at 360° instead of the static nature of a traditional documentary; E: level of satisfaction with the experience and if they would have recommended it.

3.2. Association of answers

We found a marginally non-significant association between the occupational status of the interviewees and their level of interest in environmental issues ($\chi^2 = 25.67$; df = 16, P = 0.059; see Fig. 4).

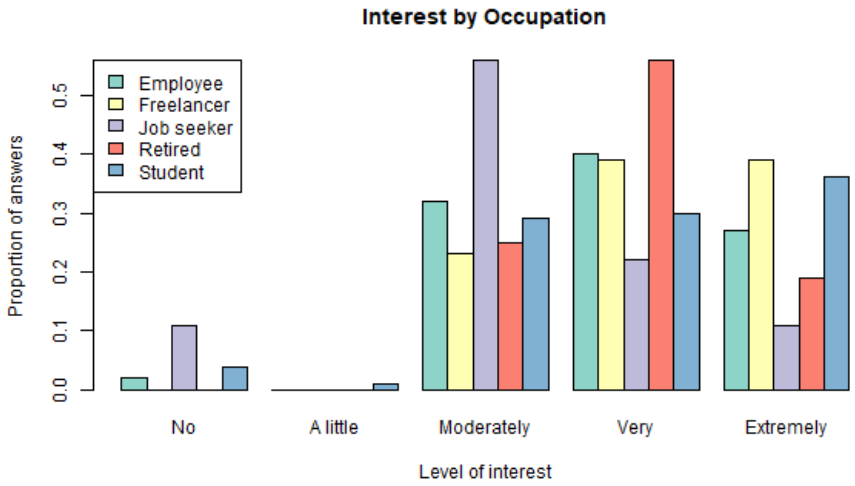

Fig. 4. Bar plot of the proportion of answers, per occupation category, for each level of interest in environmental issues.

In contrast, we found a general significant positive association between the interest in environmental topics and if VR headset could be considered as a useful tool to deepen environmental topics (χ^2 = 17.57, df = 8, P = 0.025; see Fig. 5).

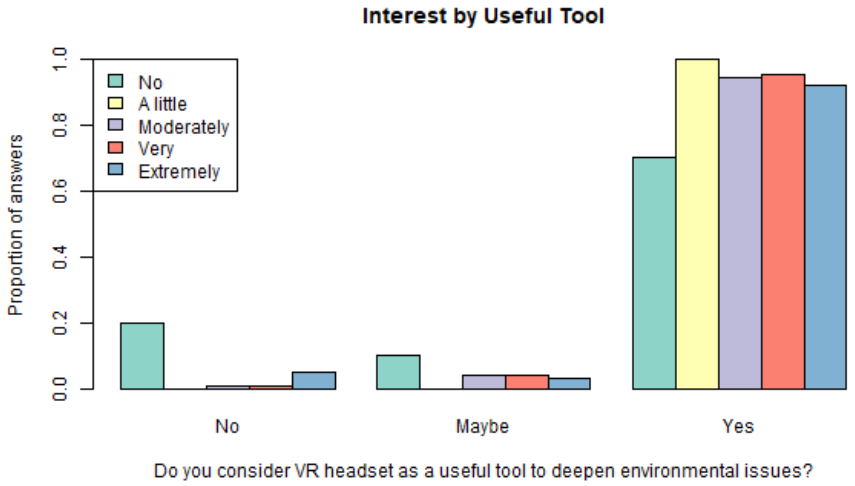

Fig. 5. Bar plot of the proportion of answers, per level of interest in environmental issues, for each possibility of considering the VR headset as a useful tool to deepen environmental issues.

The relationship between the occupational status and considering VR headsets as a useful medium to deepen environmental issues was not significant ($\chi^2 = 6.27$, df = 8, P = 0.617; see Fig. 6).

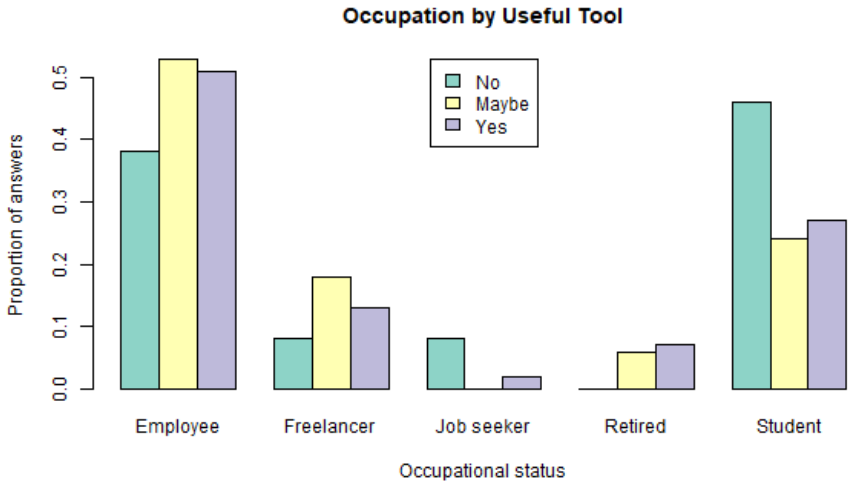

Fig. 6. Bar plot of the proportion of answers, per occupation's category, for each possibility of considering the VR headset as a useful tool to deepen environmental issues.

3.3. Satisfaction questionnaire for the operators

The operators involved in the various events were asked to express their level of satisfaction with the VR headsets though a questionnaire, with also questions based on a 5-point Likert scale. The first section of the questionnaire focused on general information about the operator, previous experiences with VR devices, and a general evaluation of the two headsets. Fifteen operators involved in the various events answered the questionnaire on their level of satisfaction with the VR headsets. Ten worked, during the events, with both devices, four with Oculus only and one with Pico only. Most of them did not have previous experience with any kind of VR headset (60%). The Oculus device was considered more user friendly and caused less issues with the public than the Pico (see Fig. 7).

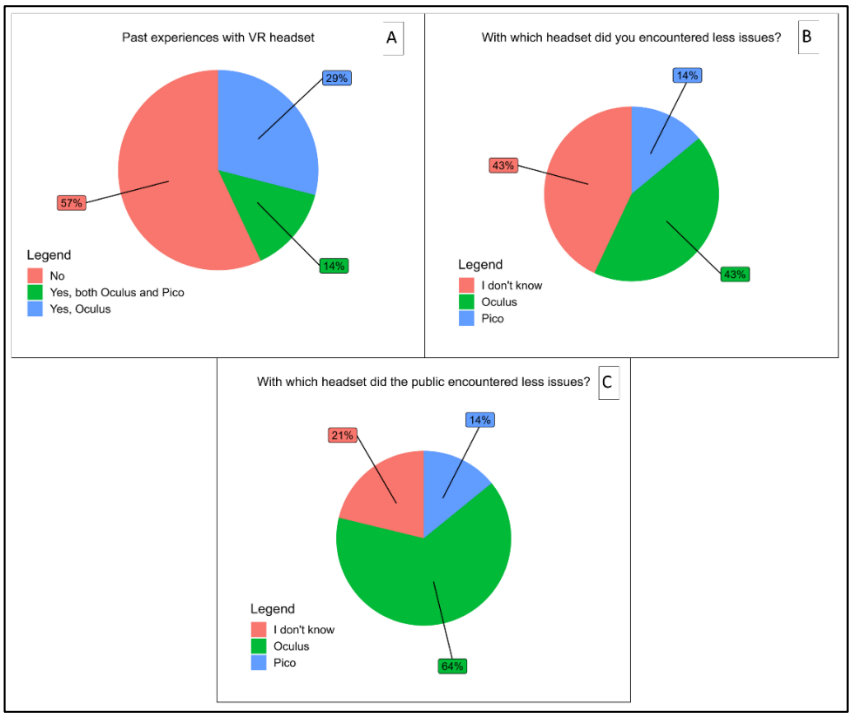

Fig. 7. Results of the questions proposed to the 15 operators after their participation in the events. A: percentage of operators which had previous experiences with VR headset and the model employed; B: percentage of answers to the question on which headset caused less issues to the operators; C: percentage of answers to the question on which headset caused less issues to the public.

The second and the third sections of the questionnaire for the operators return a score per VR device (see Fig. 8, Table 1). From these values Oculus scored a total of 3.6 over 5 points and Pico 3.5 over 5. The percentage variation was computed to quantify how much a VR device is judged better than another by the operator. The Oculus headset resulted slightly worse than PICO for three features: ease of wearing (-7.7%), video quality (-9.3%), and battery life (-12.1%). However, for the other categories Oculus device was perceived as better, especially for the user-friendliness of the software (+16.1%). In general, Oculus appeared to be slightly better than Pico headset (+2.9%).

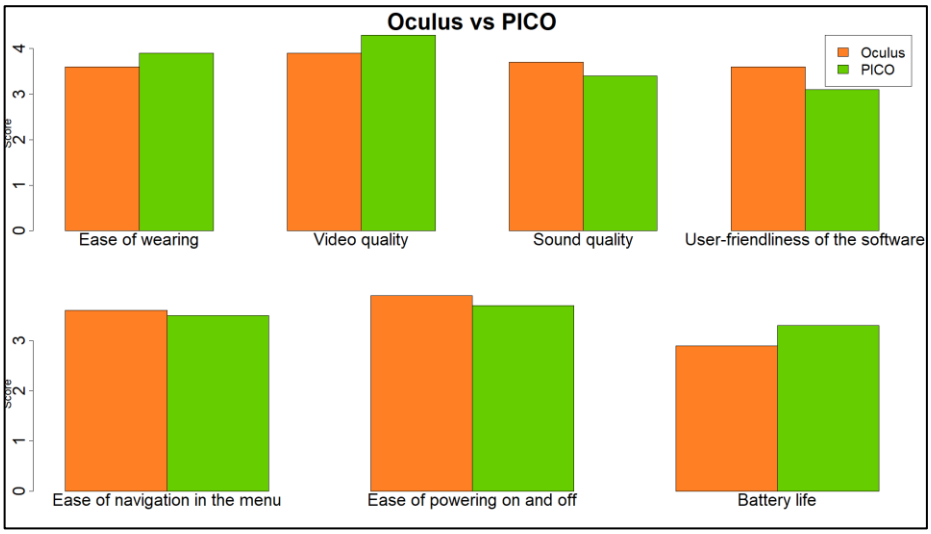

Fig. 8. Bar plot of the relative score, respectively of Oculus and PICO headset, for each feature evaluated by the operators.

Table 1. Score values of each VR device obtained from the 5-points Likert scale's questions proposed to the operators.

VR headset	Ease of wearing	Video quality	Sound quality	User-friendliness of the software	Ease of navigation in the menu	Ease of powering on and off	Battery life	Screen sensitivity to solar radiation	Total score
Oculus	3.6	3.9	3.7	3.6	3.6	3.9	2.9	3.1	3.6
Pico	3.9	4.3	3.4	3.1	3.5	3.7	3.3	3.2	3.5
Average	3.7	4.1	3.5	3.3	3.5	3.8	3.1	3.1	3.5
% variation with respect to PICO	-7.7%	-9.3%	8.8%	16.1%	2.9%	5.4%	-12.1%	3.1%	2.9%

The same questionnaire was proposed to an IT expert who has previously worked with both devices. He did not participate in the events as an operator and his answers were analyzed to highlight the different perceptions on the devices' performances. He evaluates PICO headset as better under all the aspects, except for screen sensitivity to solar radiation for which he considered both devices with the same performances (see Table 2).

Table 2. Score values of each VR device obtained from the 5-points Likert scale's questions proposed to the IT expert.

VR headset	Ease of wearing	Video quality	Sound quality	User-friendliness of the software	Ease of navigation in the menu	Ease of powering on and off	Battery life	Screen sensitivity to solar radiation	Total score
Oculus	3	3	3	3	2	2	1	1	3.5
Pico	4	4	4	4	4	3	4	1	3.5
Average	3.5	3.5	3.5	3.5	3	2.5	2.5	1	2.9
% variation with respect to PICO	-25%	-25%	-25%	-25%	-50%	-33.3%	-75%	0%	-32.3%

4. Discussion

XR technologies have the potential to greatly improve accessibility to field experience for people who may face physical or geographic barriers [25, 26]. For example, people with disabilities or limited mobility can benefit from XR experiences that offer them the opportunity to explore new environments, participate in educational activities or engage in social interactions [27, 28]. During the public engagement events we were involved in, some people with mobility disabilities had the opportunity to enjoy our immersive 360° experiences. The enthusiasm and eagerness on their part to try this type of experience was immediately apparent. In two cases, the disability also involved the upper limbs, so having VR headset that responded to eye movement to select videos allowed them to enjoy the immersive experience even without using the controller. For this reason, it is very important to adopt VR headsets that do not require a controller to maximize the level of inclusion.

Another positive feedback given refers to the fact that the immersive experiences faithfully reproduce the sites. In fact, people who have visited Villa Carlotta in person (one of the sites chosen in the "E-bike" project for enhancing cultural and natural heritage accessibility) and watched the immersive videos related to this site, confirmed that the VR headsets give the impression of being physically present (even if it is actually only virtually) at the site. This gives the opportunity to appreciate the proposed cultural and natural heritage up close.

Another advantage of proposing immersive 360° experiences during educational and public engagement events is that it makes it possible to reach a lot of people including those with disabilities and thus to make this type of event very inclusive. On the other hand, VR headsets are generally designed to be used by a single person and not worn by hundreds of different people over a single day. For example, during our events, someone complained of not being able to see well. This could be because everyone has

a different interpupillary distance (IPD, i.e. the distance between the centers of eyes). The Oculus device has a fixed IPD of 63.5mm, which accommodates users with IPDs of 61.5 to 65.5 mm. This replaces the physical adjustment (which some found rather inconvenient) that previous models required, although the supported range is consequently much lower. The Pico's IPD can be manually adjusted from 58 to 69 mm, with a default value of 63.5 mm. The mean adult IPD is around 63 mm, most adults have IPDs in the range 50-75 mm, the wider range of 45-80 mm is likely to include (almost) all adults and the minimum IPD for children (down to five years old) is around 40 mm [29]. A mismatch between the user's IPD and that assumed in creating and presenting stimuli will tend to cause problems with viewing comfort and accurate depth perception [30]. As a result, the fact that these VR headsets were continuously worn by different people increased the likelihood of experiencing problems when viewing immersive 360° experiences.

Moreover, an unavoidable feature of fairs (as in the case of "Fà la cosa giusta") or open-air locations (as in the case of "FuoriSalone") is the ambient noise that often made it difficult to hear speech during the immersive visit. However, this kind of problem was encountered more with PICOs than with Oculus. Headphones could also be used to overcome this type of problem, asking users to use their own for hygienic reasons or equipping themselves with disposable headphone covers. The issue of hygienic safety came up on one occasion when we ran out of disposable VR masks and some people, unable to wear them, preferred not to try the immersive 360° experience. On the other hand, the disposable VR masks often made it difficult to use the VR headsets because they moved around and obscured the view. The problem was that the users often did not realize this and only reported seeing everything black, thinking it was the VR headset that was not working. This was especially the case with older people generally less used to using this type of device [29], and with younger people who, having a smaller face than the disposable VR mask, had more difficulty wearing both the disposable VR mask and the VR headset.

Regarding more generally XR, computer gaming can lead to long-term changes in reward circuits that resemble the effects of substance addiction [31]. The psycho-physiological mechanisms underlying computer game addiction are mainly stress management mechanisms, emotional reactions, sensitization and reward. The first evidence that endogenous dopamine is released in the human striatum during a goal-directed motor task, namely a video game, was provided in 1998 [32]. Excessive internet video game play (EIGP) has emerged as a leading cause of behavioral and developmental problems in adolescents who have higher reward dependency [33]. In fact, computer game addicts and gamblers showed the same dopamine response to stimuli associated with their addiction presumably due to sensitization [31]. Some evidence associates video game addiction with depression, attention-deficit/hyperactivity disorder (ADHD), and obsessive-compulsive disorder [34]. Many governments already see excessive, compulsive playing of online video games as a serious adolescent public health issue and have established treatment facilities, especially in China and South Korea [35]. Many VR headset companies state that their devices are recommended for ages 13+ but there is no real regulation at legislative level [36]. During the events where we

were involved, in the case of minors we had the signed consent of the parent or accompanying adult.

From our experiences, PICO devices turned out to be slightly less user-friendly even if this does not completely correspond to technological properties, as is denoted by the IT expert score and opinions. This can be mostly because operators who voluntarily participated in the events were expert in environmental discipline rather than in IT. In fact, at all events there was no reservation to try out the experience and the flow of people interested was very variable: in some cases, there were even long queues forming at certain times of the day. For this reason, we suggest that this type of events should be done with reservation and thus have a general idea of the total number of participants.

In general, we also noted the importance of knowing the event's audience, to better capture their curiosity and to understand their pre-knowledge about the topic. Indeed, we experienced more attention and curiosity during "Fà la cosa giusta", a sustainability-centered event, than to "FuoriSalone", where the public was more intrigued by art and design's topic and laboratories. However, our results of the interviews showed that most of the people of all age ranges present at both events declared themselves interested in the topic. Moreover, our laboratories created the possibility for a large public to approach both a new form of technology, which is becoming increasingly popular, and geo-heritage sites, fundamental to increase awareness about Earth's health status. The audience, if interested, was propositional toward VR technology and, in particular, immersive 360° experiences, as a useful tool to broaden knowledge about environmental aspects and issues. This was underlined by the registered satisfaction with the unique features of this technology, such as experiencing the sounds of the environment and being able to explore the surroundings at 360°.

5. Conclusion

In this study, we discussed the efficacy of immersive 360° experiences for geoscience learning and for enhancing cultural heritage accessibility. Albeit with some criticalities, we demonstrated that this technology is useful in raising awareness about the impacts of climate change and human activities among a really large number of people and a broad age range (13 to over 65 years old). Indeed, 93% expressed a positive opinion of the effectiveness of this tool. Another objective of the experiences we proposed was not to replace the visit to the considered sites, but to stimulate knowledge about the cultural and geo-heritage, especially in those who are not attracted by environmental topics (68% declared to be extremely/very interested). During the events, we noted that whenever someone was not interested in the mountains, it was simply because they had never actually visited them. An immersive 360° experience of hiking or cycling in the mountains can arouse their desire to visit these environments. Indeed, after the immersive 360° experiences only 4% remained uninterested in the mountains and only 3% would not recommend the experiences to others.

The experience with the two different VR devices allowed us to quantify the performances, in different aspects, from the operators' perspective. Overall Oculus headset

appears to be better than PICO, and the user-friendliness of the software seems to be the preeminent quality of Oculus against its main issue that results being the battery life.

XR technology has many interactive possibilities, especially in the field of immersive 360° experiences, 3D images and sounds, and has the possibility to include other senses and human perceptual channels. It opens almost unlimited possibilities of creating innovative languages (using expressive and communicative approaches) based on the full range of human perception. Current limits depend only on technological evolution: for example, Augmentative and Alternative Communication (AAC) are essential techniques that help people with communication disabilities by replacing spoken language with symbol sequences [37]. However, to unlock its full potential, AAC materials must adhere to specific characteristics, placing the onus on educators to create custom-tailored materials and symbols. Moreover, we personally noticed over the years that deaf people are often not familiar with field excursions. Implementing videos with subtitles or sign language would make immersive videos accessible also for them. Recently, artificial intelligence can convert speech into virtual human sign language understandable by deaf people [38]. By leveraging the capabilities of increasingly modern technologies, we hope that it will be possible to implement immersive videos for geoeducation and make them enjoyable also for people with a wide range of disabilities, thus enhancing also cultural heritage accessibility. Finally, immersive 360° experiences would be offered to students in prisons to tackle physical and social barriers.

Acknowledgments

The authors acknowledge the Teaching and Learning Innovation and Multimedia Technology Centre (CTU) of the UNIMI who provided the new version of the virtual tour on the Forni Glacier accessible on smartphone and tablet without installing apps thus permitting such experience in spite of the pandemic restrictions. AlbaOptics kindly supported the project by donating some of the Oculus Go used during the events. Researchers involved in the study were supported by Sanpellegrino Levissima S.p.A., Stelvio National Park (ERSAF), ECOFIBRE s.r.l., EDILFLOOR S.p.A., Geo&tex 2000 S.p.A. and Manifattura Fontana S.p.A. Antonella Senese and Lorenzo Cresi were also funded by the Project DEEP_CHANGE (Prot. 2022MJSYF8) - Biodiversity conservation goes DEEP: integrating subterranean ecosystems into climate CHANGE agendas and biodiversity targets - funded by the Italian Research Program PRIN 2022, which is funded by the EU (NextGenerationEU funds). Veronica Manara was supported by the “Ministero dell’Università e della Ricerca” of Italy [grant FSE—REACT EU, DM 10/08/2021 n. 1062]. Maurizio Maugeri and Bruno Arcuri were also funded by the Project CCHP-ALPS (Prot. 2022CN4RWK) - Climate Change and HydroPower in the Alps - funded by the Italian Research Program PRIN 2022, which is funded by the EU (NextGenerationEU funds). The authors want to thank also the students Marta Dell'Orso and Alessandro Riccardo Nica for the help given during the “FuoriSalone” event.

References

1. Rubio-Tamayo, J.L., Barrio, M.G., García, F.G.: Immersive environments and virtual reality: Systematic review and advances in communication, interaction and simulation, (2017)
2. McLuhan, M., Fiore, Q.: The Medium is the Massage: An Inventory of Effects. (1967)
3. Page, R.: Brief history of flight simulation. SimTecT 2000 Proceedings. (2000)
4. Kavanagh, S., Luxton-Reilly, A., Wuensche, B., Plimmer, B.: A systematic review of Virtual Reality in education. (2017)
5. Diolaiuti, G.A., Pelfini, M., Maugeri, M., Ambrosini, R., Fugazza, D., Manara, V., Scaccia, D., Citron, L., Franceschini, M., Panizza, M., Senese, A.: Innovative tools for teaching geosciences: the case of immersive videos. Rendiconti Online della Società Geologica Italiana. 63, 1–8 (2024). https://doi.org/10.3301/ROL.2024.32
6. Klippel, A., Zhao, J., Jackson, K. Lou, La Femina, P., Stubbs, C., Wetzel, R., Blair, J., Wallgrün, J.O., Oprean, D.: Transforming Earth Science Education Through Immersive Experiences: Delivering on a Long Held Promise. Journal of Educational Computing Research. 57, (2019). https://doi.org/10.1177/0735633119854025
7. Senese, A., Caspani, A.C., Lombardo, L., Manara, V., Diolaiuti, G.A., Maugeri, M.: A User-Friendly Tool to Increase Awareness about Impacts of Human Daily Life Activities on Carbon Footprint. Sustainability. 16, 1976 (2024). https://doi.org/10.3390/su16051976
8. Elkins, J.T., Elkins, N.M.L.: Teaching geology in the field: Significant geoscience concept gains in entirely field-based introductory geology courses. Journal of Geoscience Education. 55, (2007). https://doi.org/10.5408/1089-9995-55.2.126
9. Fisher, P., Unwin, D.: Virtual reality in geography. In: Virtual Reality in Geography (2001)
10. Çalişkan, O.: Virtual field trips in education of earth and environmental sciences. In: Procedia - Social and Behavioral Sciences (2011)
11. 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. Geografia Fisica e Dinamica Quaternaria. 44, 67–77 (2021). https://doi.org/10.4461/GFDQ.2021.44.6
12. Diolaiuti, G., Smiraglia, C.: Changing glaciers in a changing climate: How vanishing geomorphosites have been driving deep changes in mountain landscapes and environments. Geomorphologie: Relief, Processus, Environnement. 131–152 (2010). https://doi.org/10.4000/geomorphologie.7882
13. Senese, A., Maugeri, M., Meraldi, E., Verza, G.P., Azzoni, R.S., Compostella, C., Diolaiuti, G.: Estimating the snow water equivalent on a glacierized high

elevation site (Forni Glacier, Italy). Cryosphere. 12, (2018). https://doi.org/10.5194/tc-12-1293-2018

14. Senese, A., Diolaiuti, G., Verza, G.P., Smiraglia, C.: Surface energy budget and melt amount for the years 2009 and 2010 at the Forni Glacier (Italian Alps, Lombardy). Geografia Fisica e Dinamica Quaternaria. 35, (2012). https://doi.org/10.4461/GFDQ.2012.35.7
15. Fugazza, D., Senese, A., Azzoni, R.S., Maugeri, M., Maragno, D., Diolaiuti, G.A.: New evidence of glacier darkening in the Ortles-Cevedale group from Landsat observations. Glob Planet Change. 178, (2019). https://doi.org/10.1016/j.gloplacha.2019.04.014
16. Azzoni, R.S., Fugazza, D., Zerboni, A., Senese, A., D'Agata, C., Maragno, D., Carzaniga, A., Cernuschi, M., Diolaiuti, G.A.: Evaluating high-resolution remote sensing data for reconstructing the recent evolution of supra glacial debris: A study in the Central Alps (Stelvio Park, Italy). Prog Phys Geogr. 42, (2018). https://doi.org/10.1177/0309133317749434
17. Urbini, S., Zirizzotti, A., Baskaradas, J.A., Tabacco, I.E., Cafarella, L., Senese, A., Smiraglia, C., Diolaiuti, G.: Airborne radio echo sounding (RES) measures on alpine glaciers to evaluate ice thickness and bedrock geometry: Preliminary results from pilot tests performed in the ortles-cevedale group (Italian alps). Annals of Geophysics. 60, (2017). https://doi.org/10.4401/ag-7122
18. Senese, A., Manara, V., Maugeri, M., Diolaiuti, G.A.: Comparing measured incoming shortwave and longwave radiation on a glacier surface with estimated records from satellite and off-glacier observations: A case study for the forni glacier, italy. Remote Sens (Basel). 12, (2020). https://doi.org/10.3390/rs12223719
19. Fugazza, D., Senese, A., Azzoni, R.S., Maugeri, M., Diolaiuti, G.A.: Spatial distribution of surface albedo at the Forni Glacier (Stelvio National Park, Central Italian Alps). Cold Reg Sci Technol. 125, (2016). https://doi.org/10.1016/j.coldregions.2016.02.006
20. Fugazza, D., Senese, A., Azzoni, R.S., Smiraglia, C., Cernuschi, M., Severi, D., Diolaiuti, G.A.: High-resolution mapping of glacier surface features. the uav survey of the forni glacier (Stelvio National Park, Italy). Geografia Fisica e Dinamica Quaternaria. 38, (2015). https://doi.org/10.4461/GFDQ.2015.38.03
21. Ambrosini, R., Azzoni, R.S., Pittino, F., Diolaiuti, G., Franzetti, A., Parolini, M.: First evidence of microplastic contamination in the supraglacial debris of an alpine glacier. Environmental Pollution. 253, (2019). https://doi.org/10.1016/j.envpol.2019.07.005
22. Jaroměřská, T.N., Ambrosini, R., Mazurkiewicz, M., Franzetti, A., Klimaszyk, P., Rozwalak, P., Poniecka, E., Vondrovicová, L., Zawierucha, K.: Spatial distribution and stable isotopic composition of invertebrates uncover differences between habitats on the glacier surface in the Alps. Limnology (Tokyo). 24, (2023). https://doi.org/10.1007/s10201-023-00713-w
23. Senese, A., Pelfini, M., Maragno, D., Bollati, I.M., Fugazza, D., Vaghi, L., Federici, M., Grimaldi, L., Belotti, P., Lauri, P., Ferliga, C., La Rocca, L.,

Diolaiuti, G.A.: The Role of E-Bike in Discovering Geodiversity and Geoheritage. Sustainability. 15, (2023). https://doi.org/10.3390/su15064979
24. Nemoto, T., Beglar, D.: Developing Likert-scale questionnaires. In: Sonda, N. and Krause, A. (eds.) JALT 2013 conference proceedings. pp. 1–8 (2014)
25. Morimoto, T., Kobayashi, T., Hirata, H., Otani, K., Sugimoto, M., Tsukamoto, M., Yoshihara, T., Ueno, M., Mawatari, M.: XR (Extended Reality: Virtual Reality, Augmented Reality, Mixed Reality) Technology in Spine Medicine: Status Quo and Quo Vadis, (2022)
26. Greci, L., Bosco, F., Croce, V.: The Social and hUman CeNtered XR: SUN XR Project. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (2023)
27. Kourtesis, P., Kouklari, E.C., Roussos, P., Mantas, V., Papanikolaou, K., Skaloumbakas, C., Pehlivanidis, A.: Virtual Reality Training of Social Skills in Adults with Autism Spectrum Disorder: An Examination of Acceptability, Usability, User Experience, Social Skills, and Executive Functions. Behavioral Sciences. 13, (2023). https://doi.org/10.3390/bs13040336
28. Aasen, J., Galaaen, K., Nilsson, F., Sørensen, T., Lien, L., Leonhardt, M.: Promoting Social Participation and Recovery Using Virtual Reality–Based Interventions Among People With Mental Health and Substance Use Disorders: Qualitative Study. JMIR Form Res. 7, (2023). https://doi.org/10.2196/46136
29. Dodgson, N.A.: Variation and extrema of human interpupillary distance. In: Stereoscopic Displays and Virtual Reality Systems XI (2004)
30. Hibbard, P.B., Van Dam, L.C.J., Scarfe, P.: The Implications of Interpupillary Distance Variability for Virtual Reality. In: 2020 International Conference on 3D Immersion, IC3D 2020 - Proceedings (2020)
31. Weinstein, A.M.: Computer and video game addiction-A comparison between game users and non-game users, (2010)
32. Koepp, M.J., Gunn, R.N., Lawrence, A.D., Cunningham, V.J., Dagher, A., Jones, T., Brooks, O.J., Bench, C.J., Grasby, P.M.: Evidence for striatal dopamine release during a video game. Nature. 393, (1998). https://doi.org/10.1038/30498
33. Han, D.H., Lee, Y.S., Yang, K.C., Kim, E.Y., Lyoo, I.K., Renshaw, P.F.: Dopamine genes and reward dependence in adolescents with excessive internet video game play. J Addict Med. 1, (2007). https://doi.org/10.1097/ADM.0b013e31811f465f
34. Kuss, D.J., Griffiths, M.D.: Internet and gaming addiction: A systematic literature review of neuroimaging studies, (2012)
35. Zastrow, M.: Is video game addiction really an addiction?, (2017)
36. Spiegel, J.S.: The Ethics of Virtual Reality Technology: Social Hazards and Public Policy Recommendations. Sci Eng Ethics. 24, (2018). https://doi.org/10.1007/s11948-017-9979-y
37. Elsahar, Y., Hu, S., Bouazza-Marouf, K., Kerr, D., Mansor, A.: Augmentative and alternative communication (AAC) advances: A review of configurations for individuals with a speech disability, (2019)

38. Li, X., Yang, S., Guo, H.: Application of virtual human sign language translation based on speech recognition. Speech Commun. 152, (2023). https://doi.org/10.1016/j.specom.2023.06.001