Mem. S.A.It. Vol. 94, 22

Memorie della

Extended reality technologies for public engagement and skills development

L. Daricello[1], F.A.A.S.D.T. Rometsch[2,3,4], F. Di Giacomo[5], M. Valdes[6], C. Boccato[7], V. Lombardo[8], A. Wolter[9], M.T. Menna[10], L. Licata[12], L. Leonardi[1], F. D'Alessio[10], R. Leoni[10], L.A. Antonelli[10], A.E.M. Casini[4,11], A. Drepper[4], A. Cowley[4], J.C.F. de Winter[3] and J. Guo[2]

[1] Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, 90143, Palermo, Italy
[2] Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, the Netherlands
[3] Faculty of Mechanical Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, the Netherlands
[4] European Astronaut Centre, European Space Agency, Linder Höhe, 51147 Cologne, Germany
[5] INAF – Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio, 5, 35122 Padova, Italy
e-mail: laura.daricello@inaf.it
The remaining affiliations can be found at the end of the paper.

Received: 16/01/2023; Accepted: 13/02/2023

Abstract. We will illustrate some experiences and projects presented at the VITE I conference in the field of extended reality technologies for public engagement and skill development. Extended technologies have many benefits when applied to educational contexts, providing immersive and engaging learning spaces, enhancing the sense of perception and grasp to the students, and thus improving the process of learning and motivation to access to science. Many speakers at the conference underlined that the lack of interest towards scientific topics and the difficulty in understanding science were the main problems they commonly encountered at public events, especially on the part of the young public. The use of extended realities can help overcome these problems, and is also effective for professional training in risky situations providing "a training platform that can be used multiple times for training, without worrying about the cost, availability, risk, and complexity of the equipment or system" (Doolani et al. (2020)). Moreover, when innovation generated by research responds to the need of the production companies, especially SMEs, the knowledge transfer generates a virtuous path, that stimulate the developement of our Country.

Key words. Augmented reality, Virtual reality, Extended reality, Holograms, Public engagement, Astronomy, 3D models

1. Introduction

Just to roughly define augmented and virtual reality, augmented reality "is a combination of technologies that superimposes computer-generated content over a real-world environment" (Wang et al. (2018)) and is accessible through software and mobile or wearable devices like smart glasses. Virtual reality "is an advanced, human-computer interface that simulates a realistic environment. The participants can move around in the virtual world. They can see it from different angles, reach into it, grab it and reshape it" (Zheng et al. (1998)).

Virtual and immersive environments can be explored by the use of a visor and of controllers, thus simulating experiences. The use of Virtual Reality and Augmented Reality is really effective in the communication of astronomy, both for research and for public engagement (Arcand et al. (2018)). VR allows scientists to navigate and interact with their own 3D models in virtual environments and such 3D representations can effectively visualize physical quantities like magnetic fields or velocity fields on spatial distances, thus facilitating the exploration of the universe and making the analysis and the understanding of astronomical data much easier.

Furthermore, the ease of portability of VR devices like Oculus or smartphones enables to set up AR and VR experiences in classrooms and at various public outreach events. Nevertheless, despite the broad proliferation of VR and AR tools in consumer culture, still, only a small minority of institutions currently use these technologies. Moreover, VR and AR have been recognized as very powerful and effective tools for the enhancement and fruition of cultural heritage (Bekele et al. (2018)): by adding information to the real-world environment, AR technology improves the users' experience by overlaying insights and multimedia information, and all these contents are accessible with a common smartphone. By reproducing a real environment, VR – and in particular 3D models and 3D prints of cultural artifacts preserved in museums - allow direct interaction and manipulation and offer visitors a direct experience. New technologies such as Virtual Reality (VR) and Augmented Reality (AR) have already been used as training tools in a variety of domains – e.g. in the fields of education, public engagement, simulating emergency situations, etc. Anyway, to develop an effective product, some good practice has to be followed and, particularly, products must be user-centered, simple to use, and engaging and precise objectives and high technical/scientific value contents have to be previously well fixed. Since this kind of product has to allow emotional experiences, the tool must recreate the illusion of being in an "other place" or, for example, it has to perfectly integrate contents with the real environment, depending on the technology chosen.

Some experiences presented at the VITE I conference are illustrated below, in order to give an overview of different contexts where extended technologies can be used, form the case of professional astronaut training, to some experiences developed by the Italian National Institute for Astrophysics (INAF) – to communicate astronomy projects like the Cherenkov telescopes array ASTRI Pathfinder and the SKA radio telescopes, to explain how the Cherenkov telescope works and which are the sources of high energy photons, to describe how the water molecule formed in space, how it is maintained in the cosmic vacuum and how it arrived on Earth, the realization of the first holographic theatre for scientific outreach. Moreover, we will illustrate an experience developed by INGV to bring the user to visit the interior of an ideal volcano and two VR projects and a short animation movie developed by a private company, specialized in the production of multimedia material for scientific dissemination based on innovative digital systems.

2. The PRIN INAF project "Virtual Reality and Augmented Reality for Science, Education and Outreach"

The PRIN DIV INAF project "Virtual and Augmented Reality for Scientific Research, Education and Outreach" (see Fig. 1), was conceived starting from the assumption that virtual and augmented reality, enriching our experi-

ences and changing user attitudes, can successfully be used in a visual science like astronomy for science (Orlando et al. (2019)), for public engagement activities and events (Impey & Danehy (2022)), for education and skill development (Xie et al. (2021); Kersting et al. (2021)) and for the enhancement of scientific cultural heritage (Zanazzi, et al. (2021)).

Launched in February 2021, the project involves 9 INAF structures - Palermo OA, Palermo IASF, Bologna OAS, Catania OA, Osservatorio d'Abruzzo, OA Capodimonte, Trieste OA, Arcetri OA, OA Roma - and numerous researchers.

Taking advantage of innovative technologies, the project has supported research, education and outreach activities, in the creation of science content and in knowledge transfer. In the initial phase of the project, we shared the experiences and the activities related to virtual and augmented reality that had been carried on, before the beginning of the project, in many INAF structures (see Fig. 2). This overview showed that there were a variety of experiences, using different hardware and software, for various goals and in different ways. Afterwards, we organized a virtual training school to share technological expertise and to transfer skills and competences within our institution, thus allowing INAF researchers and technologists involved in the project to create their own visualization tools for outreach, education and communication purposes. Some tutorials of the courses are available online, from the project website1. In the first 30 months of the project, we have conducted innovative experimental research in the study of VR/AR technologies and in the development of collaborative virtual reality environments, computer graphics and chroma key techniques, and developed new models and exhibitions to be used in VR and AR to explore the world of astronomy, thus promoting the understanding of even the most complex topics and demonstrating the usefulness and the beauty of science. (see Fig. 3). Immersive 3D models and storytelling dynamics are indeed a solution to actively engage the learners in interacting with science and increase their access to practical scientific education (Leonardi et al. (2021)). Among these studies, the experimentation of virtual environments where researchers and educators could virtually meet the students and the public, like the "High Energy Museum", where users can access and interact with some of the simulations of astrophysical phenomena created within the 3DMAP-VR project. Original resources developed within the project – or resources on which members of the working group collaborated - are available on the web page of the PRIN project[1]. The AR and VR sections[2] have been added to the PLAY website – the INAF repository of educational innovative resources.

Within the PRIN, collaborations with European projects have been developed and, in particular, some researchers were invited to collaborate in the international project ACO (Astro-Chemical Origins), H2020 EC Marie Skłodowska-Curie Actions, as teachers in a VR school in Padua [3](July 2021). Researchers involved in the PRIN, during the 2021-2022 school period carried on the project for schools "From research to school and society: technological revolution and e-education initiatives", financed by Assessorato dell'Istruzione e della Formazione della Regione Siciliana. Moreover, we participated in many national and international meetings to present the outcome of our research and gain knowledge on the newest products and solutions in the field of VR/AR and ICT at large.
Furthermore, the team developed many virtual environments of INAF facilities and museums and the "astronomical routes" of the pilot project in the field of astro tourism "Seconda stella a destra"[4], by INAF and Bas Bleu, was completed and integrated with AR contents. The meeting "Virtual Reality and Augmented Reality for the dissemination of science: new frontiers and new challenges" was organized

[1] https://axt.oapa.inaf.it/prin-vrar/

[2] https://play.inaf.it/risorse/realta-aumentata/; https://play.inaf.it/risorse/realta-virtuale/

[3] https://aco-itn.oapd.inaf.it/events/aco-schools/aco-virtual-reality-school

[4] Palermo. Seconda stella a destra (2021), M.L., Tuscano, et al., Les Bas Bleu ISBN: 9788890411854, Codice EAN: 9788890411854

Fig. 1. The courses proposed in the virtual training school.

within the framework of the PRIN, to present the outcomes of the project, and to start a discussion within INAF and between research institutions, universities, schools, public institutions and private individuals and companies operating in the same field, to deepen the knowledge of these technologies and their use for research and public engagement, and to build a network of collaboration that can expand the work done so far.

3. eXtended Reality for Astronaut Training and Operations

A study conducted by Flavie Rometsch for the thesis of the Master of Science in Space Engineering e Mechanical Engineering (BioRobotics) – and carried on in collaboration with researchers of Delft University of Technology and EAC ESA – illustrates the use of eXtended Reality for Astronaut Training (Rometsch et al. (2022)). Extravehicular activities (EVAs) will represent a crucial part of the scientific activities to be carried out during future crewed space missions to the Moon, Mars and beyond and will involve extensive geological fieldwork. These EVAs entail many challenges as real-time ground support cannot be provided to astronauts during these operations. Therefore, modern human-machine interfaces have to be designed to support astronauts, during their deep space missions, by enhancing their mission autonomy and reducing ground communication dependability for real-time operations.

Several studies have been performed on the effectiveness of Augmented Reality (AR) in assisting procedure-guided tasks for both on-board and on-ground operations; however, so far, none has focused on the development of a tool capable of supporting astronauts during geological fieldwork, particularly geological site inspections. Based on the research currently performed regarding Internet of Things (IoT) technologies in combination with AR for visualization and enhanced situational awareness purposes and, accounting for the lessons learnt from the Apollo program, the International Space Station, and several analogue mission campaigns, the present work investigates the benefits obtained through the use of these technologies applied to future planetary and lunar human space exploration.

This study presents an AR-IoT tool for astronauts to carry out geological activities (see Figure 4). It proposes a theoretically-informed user-centred design method supported by expert feedback and an evaluation method. The

Fig. 2. The courses proposed in the virtual training school.

tool was assessed via questionnaires and semi-structured interviews with ESA astronauts and geological field activities experts, at the European Astronaut Centre. A qualitative content analysis of the interviews showed that user satisfaction was the first most mentioned (32% of 139 quotes), and therefore the most important usability component. Key design factors identified include: displaying solely important information in the field of view while adjusting it to the user's visual acuity, extensibility, simplicity and easy usage. The second most mentioned (24% of 139 quotes) usability aspect, and therefore the second aspect in order of importance, was user interaction, with voice seen as the most intuitive input. Finally, this research accentuates important factors determining the usability and operational feasibility of an AR tool for astronaut analogue training missions and provides a foundation for future design iterations and an eventual integration of AR into the spacesuit's visor. As shown, the most considered usability aspects by professional astronauts are user satisfaction and user interaction. Utility is definitely an important aspect, but it was not the most important, probably because a tool is useful when it is has a high degree of usability that can be defined as "The extent to which a product can be used by specific users to achieve specific objectives with effectiveness, efficiency and satisfaction in a given context of use" (Rometsch et al.

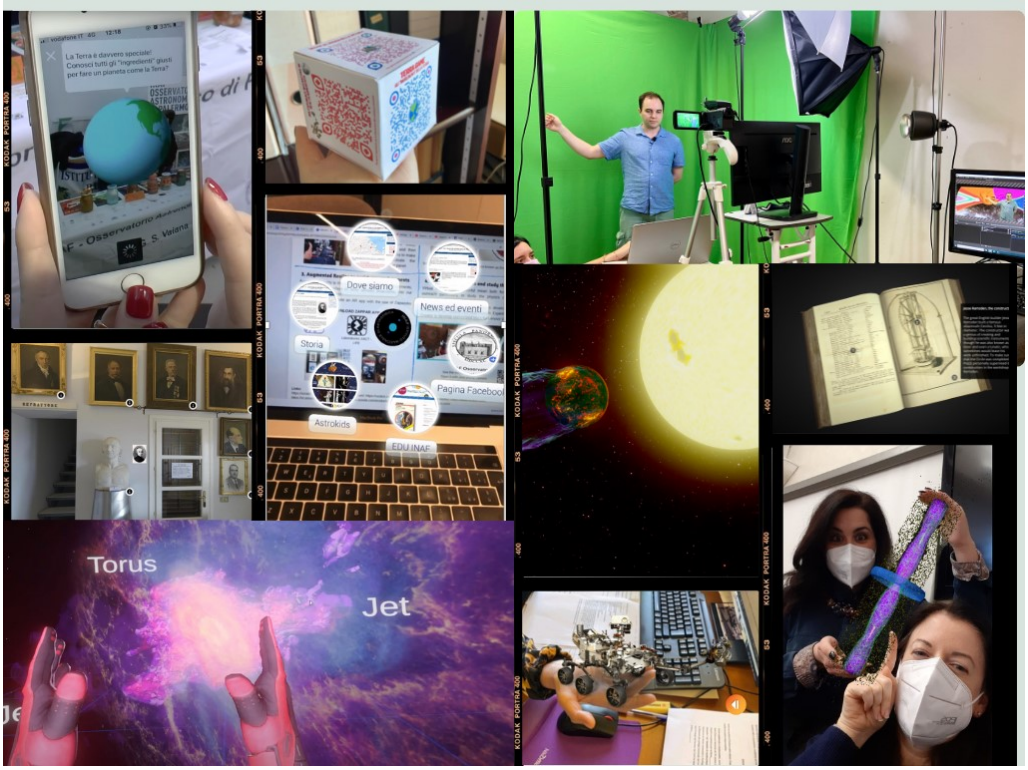

Fig. 3. Some examples of the research activities carried on.

Fig. 4. Analogue astronaut Fouchet with Microsoft HoloLens running the AR-IoT tool during a Mars Desert Research Station (MDRS) analogue mission in Utah, US (credits: MDRS Crew 263).

(2022)). Among the negative aspects detected in this research, the technology readiness level of Microsoft HoloLens.

4. The "Virtual Present" for the "Real Near Future" INAF in SKA and CTA

Usually when you think about virtual reality (VR) you might conjure up images of video games or immersive tours of deep ocean waters or in another exotic location. However, VR is also an exciting tool both for research, and for outreach and educational activities. An example of this is the VR exhibit realized by INAF, to describe two projects of the near future: the Cherenkov telescopes array ASTRI Pathfinder and the SKA radio telescopes. The main goal of this exhibit is to use the "wow effect" to capture the interest of younger people, but not only, and to show the contribution of INAF in these two projects, providing a series of specific contents about the science and technology of ASTRI and SKA.

This exhibit was realized in the context of the PRIN 2016. In this background three

Fig. 5. Picture of CicerOne greeting the user inside the virtual environment

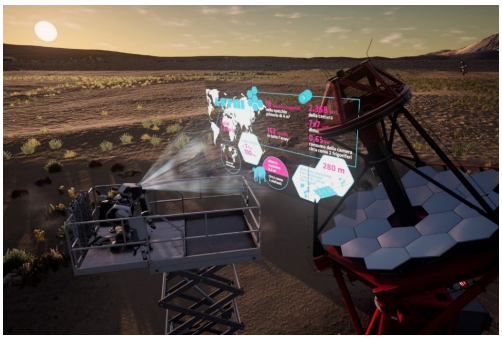

Fig. 6. Picture of CicerOne above one of the ASTRI array telescopes. Here CicerOne shows an infographic with the characteristics of these telescopes

Fig. 7. Picture of CicerOne above one of the ASTRI array telescopes. Here CicerOne shows an infographic with the characteristics of these telescopes

projects connected with ASTRI[5] and three with SKA[6] were financed, and thanks to the will and coordination of Sector D of the INAF Communication Structure, and in agreement with the PIs of the projects, the various resources were shared to realize a very high innovative VR product. To realize this exhibit, we decided to commit the creation of the VR software to the ASSA s.r.l., a company specialized in CGI, the component of Computer Graphics that allows the creation of virtual environments, images and 3D videos. In the first step of the project, an extremely precise storyboard was realized to describe in detail both the contents to be provided to the users, the interactions, and everything that the users can do in the virtual environment. To guide users in the virtual environment and to describe the science and technology of SKA and ASTRI, we decided to create a robot, with anthropomorphic features, named CiceroOne (see Figure 5). Thanks to its virtual eye, CicerOne can project videos and infographics to describe the characteristics of these two projects (see Figure 6 and Figure 7).

From the hardware point of view, the workstation consists of an HTC-Vive viewer and two knobs, which allow the user to move and interact within the virtual environment, all connected to a PC that contains the VR application. This workstation allows us to obtain maximum resolution and immersion but, on the other hand, it allows the use of the experience by a single user at a time.

Since its realization, this exhibit has been presented during the science festival of Genoa and Naples in 2019. Beyond these two installations it was not possible to take it elsewhere due to the Covid-19 pandemic which made the use of these technologies impossible. This virtual reality activity, due to its high resolution graphics and complexity, requires a dedicated workstation with very high performance. For this reason, this experience can only be used in contexts such as festivals or other public events. A possible development could concern

[5] ASTRI web site: `http://astri.me.oa-brera.inaf.it`

[6] ASKA web site: `https://www.skatelescope.org/the-ska-project/`

the realization of a portable version of this VR experience (for example with Oculus) in order to allow everyone to be able to discover the characteristics of ASTRI and SKA.

5. Grab that photon! A simple but effective way of using Augmented Reality and Virtual Reality for INDACO outreach programs

The realization of a Zappar app within the activities of the group INDACO - INAF per la Divulgazione di Astri[7] e CTA-Observatory[8] - shows that it is not too complicated to produce an effective tool in augmented reality for any kind of project, even scientific ones. The highest energy photons are very difficult to catch: we need huge instruments, large collecting area (i.e. big telescopes) and very fast receivers. This is because to measure the energy carried by a single photon, you need to somehow stop it and make it release all the energy into your instrument. And stopping high energy photons becomes an increasingly difficult task with increasing energy. Since a few decades, we know how to do it, by exploiting the Earth's atmosphere, which produces a shower of particles when hit by a very energetic photon. These particles fly, for a few nanoseconds, at a speed larger than the speed of light in air, producing blue Cherenkov light. We construct telescopes with large mirrors and very fast electronics to collect this blue short-lived light.

Our tool, constructed with the WebAR platform Zappworks, is called "ASTRI Mini-(AR)ray", where the "AR" hints to Augmented Reality. The project has been led by Giuseppe Fiasconaro, with the help of many INDACO people. It allows the viewer to learn about an overview of the project (see Figure 8), to understand how the telescope works, which are the interesting celestial sources of high energy photons. The project has gone through different phases: layout of the structure, searching

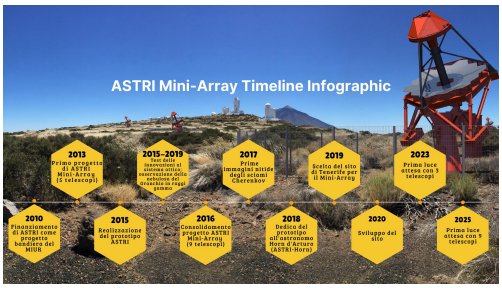

Fig. 8. The timeline infographic for ASTRI Mini-Array realized during the project

for existing material, production of new videos when needed, audio recordings, final mounting. We had in house video and audio expertise. We could also exploit, through the nationally founded project (Prin "Virtual reality and augmented reality for science, education and outreach") of INAF lead by Osservatorio Astronomico di Palermo, a few lessons on the use of the Zappworks utility, in its free distribution. The work took about a month, spread over a period of a few months, involving a small group of dedicated colleagues.

The final product has been used already in a few events, like the Festival della Scienza in Genova, or the Festival dell'Astronomia in Castellaro Lagusello (MN). Scan the QR codes in Figure 9. The result is encouraging for the next project, in which we aim at producing small modular elements of 3D renderings of the telescopes or parts thereof, so that they can be assembled in different "stories", and easily updated when necessary. Using an easy and light device like the oculus ensures also a wide distribution. This last part will be realized in the framework of the PNRR funded CTA+ project, led by INAF with collaboration from INFN and CTA.

6. "The shape of water" - Virtual Reality for transversal skills in a co-design perspective

"The shape of water" is a Virtual Reality experience for the public, made in the framework of the Horizon 2020 Programme, in particular for the scientific research project

[7] ASTRI web site: `http://www.astri.inaf.it/en/`

[8] CTA Observatory: `https://www.cta-observatory.org/`

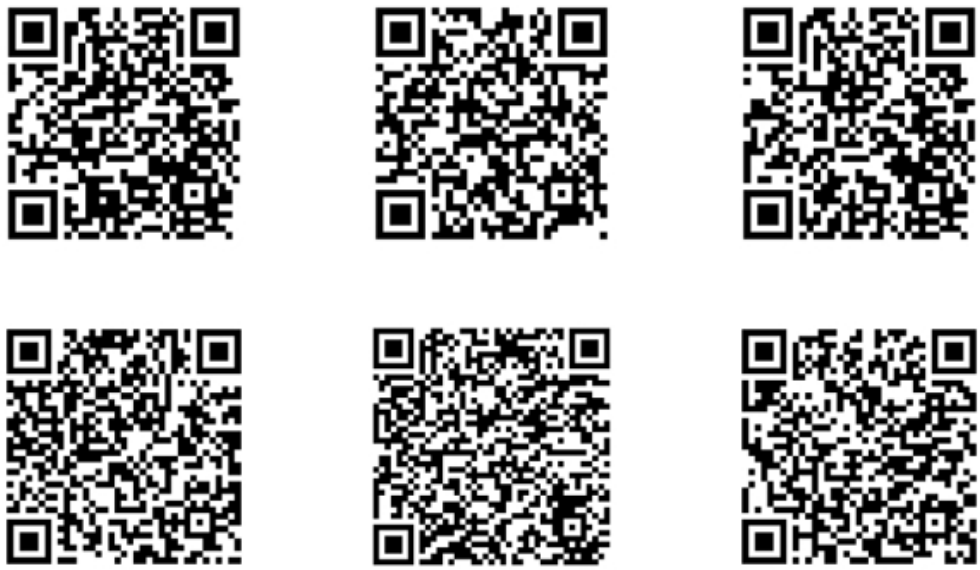

Fig. 9. Above, there are a few videos on the project - on the Facebook page of the Congress; below, ASTRI at the Festival della Scienza di Genova

AstroChemical Origins[9]. ACO is a collaborative network of several European institutes and companies, funded in 2018. Its twofold goal is to reveal the past Solar System history, using Astrochemistry as a tool, and train a new generation of interdisciplinary researchers.

Seventeen young researchers have been recruited from eleven Countries all over the World and from different disciplines such as astrophysics, chemistry, engineering, and computer science. Among the outputs of the project, in addition to scientific production, the creation of a series of deliverables, aimed at disseminating the project itself and the science that underlies it, occupied a place of primary importance. One of them was an Immersive Virtual Reality product for the general public.

As a MSCA-Innovative Training Network, one of the specific objectives of ACO was the acquisition, by young PhDs, of the so-called transferable skills, in order to "equip" them to face and overcome the new challenges of the contemporary world so as to play a key role in the progress of science and of tomorrow's society. This means that they must not limit themselves to solving purely scientific problems but have also to work in a team, manage projects, develop critical thinking, understand the difference between the academic world and the industrial one, and finally communicate, at all levels, the results they get. It's important to stress that the transversal skills listed above would not be acquired in creating the product, however complex, but in the product design process. This is the main reason why the general aspect on which I insisted with them was also thinking of an overall project for the realization of the virtual reality experience. This means to settle the values, the target, the goal, the objectives, and a strategic communication plan. All the PhD students actively worked on the project, with a co-creating methodology applied during the two schools, and then each of them focused on different aspects according to a tasks' table. A playful educational VR experience has been realized (see Figure 10).

In it the user can play and learn at the same time how the water molecule formed in space, how it is maintained in the cold and

[9] The ACO project - `https://aco-itn.oapd.inaf.it/sait`

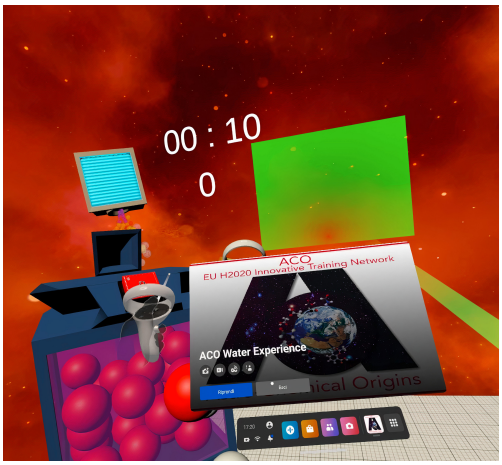

Fig. 10. Inside the ACO VR experience, the first game in which you have to build water molecules using oxygen and hydrogen atoms

cosmic vacuum, how it arrived in such great abundance on Earth. The VR Experience has been successfully presented in the European Researchers' Night '22 and the Genova Science Festival. The experience will be soon released in the testing channel, and after the first test phase it will be freely accessible on the ACO website.

7. The realization of the first holographic theatre for scientific outreach at INAF OAR

During the past year we were presented with the opportunity to renovate the Astrolab, the science museum located in the Monteporzio Catone Observatory astronomical park, which was established in the year 2000, thanks to funding coming from the S.U.S.A. project, which stands for Smart Urban Sustainable Area. It establishes a new cooperative approach between science organizations, citizens and political institutions in an area, in the southern quadrant of Rome, which is packed with scientific institutions. This allowed us to not only renovate the whole exposition, but to aim to create a new, modern exhibit, with a "wow" factor to engage the young visitors in scientific contents. Our preferred choice was a holographic display, namely a device able to reproduce images and videos with a tridimensional effect. Though real holography is limited to static images, there are now several solutions, commercially available, which by different artifices are able to reproduce convincingly moving tridimensional objects. Our preference was for Naumachia, an Italian company which has developed several holographic devices, from tiny sizes to be hosted on a bookshelf to human size apparatus to holographic theaters in which one is able to represent objects on a stage alongside a human presenter. Moreover, a valuable feature of this kind of device, is that it allows a holographic telepresence with a remote guest just using a green screen and a common camera. Having done some preliminary feasibility study, this was our choice, to be installed in the upper floor of the Astrolab, with 30 seats.

Another important part of the exhibit development was the choice and creation of suitable subjects to be displayed on stage to reveal the full potential of the Holotheater. Some content was developed on purpose by Naumachia in collaboration with our group, for example a rotating constellation to show that it is a group of stars with a significance only as viewed in projection from a special position. Some material was kindly provided by colleagues, such as Salvatore Orlando (INAF OAPa) which had created 3D representations of several astronomical objects from numerical models (Orlando et al. (2019)). The main part of the inaugural presentation though, was devote to numerical 3D simulations of accreting black holes and black hole mergers, created by NASA Goddard scientist Jeremy Schnittman, in which the OAR Director Antonelli was able to interact with the objects on display (see Figure 11). We were also able to invite Dr. Schnittman on stage with us on the occasion of the inaugural evening, on the 15th of March 2022, to interact live with the public and press.

8. Virtual Reality in science education: Volcano 3D

"Volcano 3D" is a new software developed by INGV that uses virtual reality (VR) to bring the

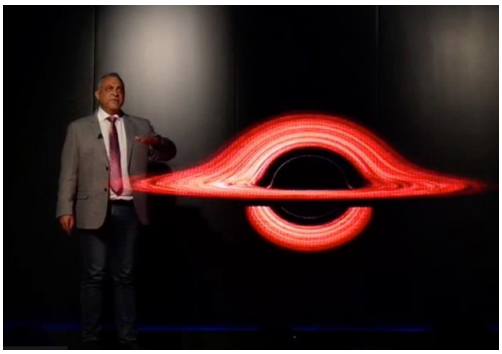

Fig. 11. The holostage inauguration

viewer to visit the interior of an ideal volcano, on which to carry out experimental measurements. Users are asked to perform actions such as measuring the lava temperature and the volcanic gas emission concentration. On one side, students and teachers are involved in scientific research activity; on the other side scientists are asked to become involved in outreach and educative activities and to spread their knowledge outside the laboratories. It has been developed with Unity 3D and uses the HTC Vive VR technology to provide an immersive experience in digital virtual environments. Unlike other traditional user interfaces, VR places the user within an experience: instead of viewing a screen in front of them, users are immersed in and able to interact with virtual 3D worlds in which all their senses can be simulated. Thanks to a steadily growing number of wearable headsets and ad hoc applications, virtual reality systems offer new opportunities not only in entertainment and gaming, but also education and scientific dissemination.

Considering that childhood is a crucial phase for the growth of the human mind, especially important for the development of knowledge and skills, we propose to realize an educational video game to teach geophysics and Earth sciences to high and low-school students. Geophysics is the application of the laws and techniques of physics to uncover knowledge about the earth's dynamic processes and subsurface structure. It explores phenomena such as earthquakes, volcanoes, tsunamis to improve our understanding of the earth's physical processes and our ability to predict reoccurrences.

The HTC Vive headset technology, used by "Volcano 3D", is the first virtual reality system that allows total freedom of movement. While conventional VR glasses only control the viewing direction, with HTC Vive, you can move around in a virtual space with additional controllers. This system allows an immersive experience in the simulated environment. "Volcano 3D" was developed using Unity 3D. The engine can be used to create three-dimensional (3D) and two-dimensional (2D) games, as well as interactive simulations and other experiences. Unity 3D is fully compatible with HTC Vive technology, but can also be easily adapted to use with other VR systems.

The specific objective of this project is to develop a video game to teach geophysics at school and to receive feedback from students on this new educational method (see a student testing the project in Figure 12). The objective has different functions:

a) the experimentation of new technologies, such as VR, in projecting and implementing didactic activities;
b) the achievement of technological scientific professionalism, highly requested from the current development needs. Moreover, the educative action can provide skills and abilities in computer graphics and multimedia;
c) widespread dissemination of information and education to reach student families.

"Volcano 3D" has been used in various scientific dissemination events such as Open Science, Living Planet organized by the European Space Agency (13 - 17 May 2019), the Science Festival organized by National Geographic at the Auditorium in Rome (8 - April 14, 2019) and for the twentieth anniversary of the INGV.

Fig. 12. Scientific and engineering studies can largely benefit from Virtual Reality technology

Fig. 13. Scientific and engineering studies can largely benefit from Virtual Reality technology

Fig. 14. Immersive view of the Galapagos Islands in You Are Darwin VR

9. Virtual Reality and Animation as Tools for Innovative Science Dissemination

VIS (Virtual Immersions in Science) - innovative startup and first ever spinoff in the history of the Scuola Normale Superiore (SNS) - specializes in the production of multimedia material for scientific dissemination based on innovative digital systems. We present two VR projects and a short animation movie aimed at inclusive science dissemination to the public. The first project, "Moon Landing VR", is a virtual reality game/simulation that combines physical realism with the exciting challenge of having to manage rocket fuel and adjust the Lunar Module speed to land softly. Thanks to VR technology, the user climbs aboard Apollo 11 to experience first-hand the most famous moon landing in contemporary history (see Figure 13).

The highly entertaining immersive experience has an educational focus: thanks to the right balance between realistic physics and playability, every user can learn first-hand what it feels like to land on the Moon, where gravity is about one sixth of Earth's. Moon Landing has been presented at public events such as Focus Live, Expo Dubai, Meet Digital Center, and is the first building block of a mixed-media educational experience that will include short animation videos and interactive lessons, open to school students and to the broad public.

The second VR project, "You Are Darwin" (YAD), is an immersive exhibit inaugurated at the Kosmos Museum in Pavia in October 2022. Charles Darwin, at the age of 22, made a voyage around the world aboard the ship Beagle. The observations of nature he made during his voyage would form the basis of the theory he would later develop for the rest of his life. Thanks to YAD the user is able to travel as Darwin to some of the places he visited, and relive his discoveries (see Figure 14). The narrative voice and guide is Darwin himself: his words are freely drawn from his most famous writings. The nature of the tour is both emotional and technological and changes the way a Natural History Museum like Kosmos is perceived and experienced. The real innovation is the hybrid nature of the experience, which leads to experiencing Virtual Reality while moving through a real space. For the first time, it is possible to observe the Museum's

Fig. 15. Official poster for "Pulsars: a Tour of Cosmic Clocks"

collections while simultaneously virtually immersing oneself in the environments that allowed the great English naturalist to formulate his theory of evolution by natural selection. The feedback from the public (already of the order of one thousand visitors despite the limited number of guided tours and the compulsory online booking) has been outstandingly positive thanks to its innovative hybrid nature. In the next months we will gather data to assess the impact of the VR experience on the Museum visit, a topic that has been studied in the past but is still in its infancy.

Finally, we introduce our short film "Pulsars: a Tale of Cosmic Clocks", a EU funded collaboration to communicate the science of astronomical compact objects such as pulsars and black holes to a broad public, addressing at the same time the fundamental role of women in science to motivate school girls to consider a career in science (see the official poster in Figure 15). To tackle the challenging objectives, we followed an innovative approach, mixing live action footage and animation to build a compelling storytelling and to increase the empathic response of youngsters - especially high school girls, such as the lead character Alma. At the same time the screenplay was carefully tuned to convey rigorous scientific information on pulsars and black holes in an entertaining way. The animation layouts with cosmic objects and events were rendered using an innovative algorithm, which reduces rendering times considerably, without sacrificing quality. We managed to achieve a seemingly 2D rendition of 3D complex objects with pencil and crayon like strokes and close enough scientific precision. The processes chosen optimized time and effort, reducing the time/cost factor of the whole production. The short film has been awarded the "Science in Action" prize and the Raw Science Film Festival award in 2022.

The VR projects "Moon Landing" and "You Are Darwin" are commercially available to museums, exhibits and events, and have already been viewed by an estimated 20.000 users both at the Kosmos Natural History Museum in Pavia and during promotional events attended by VIS, with the number of users steadily increasing. The short film "Pulsars: a Tale of Cosmic Clocks", being a EU funded project, is available to the public on VIS Vimeo channel[10] or on the Youtube channel[11] of the Institute of Space Sciences.

10. Research projects as contributions to the development of VR and AR technology

The activities of a research institute such as the Istituto Euro-Mediterraneo di Scienza e Tecnologia (IEMEST)[12] are aimed at responding to the need to transfer the knowledge deriving from industrial research and experimental development to the production companies themselves. The projects therefore represent the link between the innovation needs

[10] https://vimeo.com/manage/videos/706964021

[11] https://www.youtube.com/watch?v=2O3T2RXJiwg

[12] https://tinyurl.com/5n7wxzbf

of companies, especially SMEs, and the process/product, thus creating a virtuous path that transfers the innovation generated by research directly to the product.

The contribution of the partners is important in this process, as are the insights deriving from the conclusions of the interdisciplinary thematic tables, in which the topics are explored with the contribution of different training experiences ranging from physicists to psychologists or from engineers to humanists and with the competition of experienced researchers, professionals from production activities and interns and young graduates who from this experience acquire knowledge in terms of working method and completion of training. The method adopted, consolidated by numerous projects and by multiple meetings, supported by a network of contacts strengthened by memoranda of understanding and agreements and by planning aimed at participation in national and international tenders in various fields, linked to higher education activities through masters, specialization courses in various fields, is the basis of the way IEMEST operates. This method has found particular application in the structures and technologies connected to VR and AR which, through a research project called "3DLab Sicilia"[13], have made possible to design and build a liquid laboratory, to train young resources in the field of technologies suitable for the virtual and augmented reality product, to involve both local companies, public and private research structures, to provide services aimed at optimizing processes/products, enhancing cultural heritage, analysing the stability of buildings, creating a regional network of laboratories, interconnected and connectable with similar realities, in order to respond to the needs of companies, research structures, design studios.

The example of the IEMEST liquid laboratory, made up of a CAVE (Cave Automatic Virtual Environment) or Immersive room - a physical space in which it is possible interact with the virtual through special virtual reality programs and the use of sensors and video projections, and viewers of various types - is a demonstration of how the multidisciplinary method adopted by the Institute can represent an asset for the territory, but also of how a research project can favour the growth of knowledge (see Figure 16). Virtual and augmented reality, which increasingly represents a tool at the service of the scientific community, constitutes, also through the IEMEST laboratory, a point of reference for the territory and for the companies that operate in it. Various Innovative Technological Experiences (VITE I), the conference dedicated to it and to which the IEMEST scientific community has contributed, opening a window on these innovative technologies, has allowed not only the comparison between different ways of responding to the connected problems, but also a moment of knowledge and comparison, thus starting a synergistic process both horizontally, between the makers of these technologies, but also vertically, i.e. between makers and potential users. The possibility of comparison, the verification of the results achieved, the different quality of the products, allowed the participants to take stock of the technologies connected to VR and XR, but also to identify the new frontiers and new challenges that pertain to this particular area of dissemination of science.

Fig. 16. IEMEST's CAVE

11. Conclusions

This article provided a panoramic of the talks presented at the VITE I conference in the field of public engagement and skill development with new technologies. The speakers il-

[13] https://www.3dlab-sicilia.it/en/attivita/

lustrated some negative aspects and problems encountered, such as:

- the portability of some installations, which need a high performance workstation to work
- problems related to internet connection
- technological limitations due to the hardware chosen
- in some cases a user, who isn't already familiar with the technology can find difficulties in using the software
- some people experience a feeling of discomfort, especially when using VR
- the use of VR helmets in some cases limits the presence of large groups and classrooms
- Some applications take a long time to be experienced and aren't fit to be used at festivals or with a multitude of people.

However, the experiences illustrated confirmed that:

- People are willing to invest their time in testing innovative hardware and software
- Due to its distinctive features, all these extended reality technologies allow interactive experiences that can stimulate all the senses, thus facilitating comprehension and knowledge acquisition
- Innovative technologies promote a positive attitude of the public/learner towards the contents presented
- The co-presence of audio, video, images and playful and interactive elements also solicits the emotional sphere of the public and allows the conveyed contents to be acquired more pleasantly and in less time. Finally, extended reality empowers people to construct new knowledge and expertise through experience, which is the best way of learning, acquiring and remembering contents.

Affiliations

[6] VIS srl, Piazza dei Cavalieri 7, 56126 Pisa, Italy
[7] INAF Public Outreach & Education Office
[8] INGV, Via di Vigna Murata, 605, 00143 Rome, Italy
[9] INAF - Osservatorio Astronomico di Brera, Via Brera, 28, 20121 Milano MI
[10] Istituto Nazionale di Astrofisica - Osservatorio Astronomico di Roma, via Frascati 33, Monte Porzio Catone, 00078, Italy
[11] Agenzia Spaziale Italiana (ASI), Via del Politecnico, 00133 Rome, Italy
[12] Istituto Euro-Mediterraneo di Scienza e Tecnologia (IEMEST), Via Michele Miraglia 20, 90139 Palermo, Italy

References

Arcand, K. K., et al., Walking through an exploded star: rendering supernova remnant Cassiopeia A into Virtual Reality, CAPjournal, 24, 17-24

Bekele, M. K., et al., A survey of augmented, virtual, and mixed reality for cultural heritage. Journal on Computing and Cultural Heritage (JOCCH), 11(2), 1-36, 2005

Borrego, A., et al. 2018, Games for Health Journal, 151-156

Doolani, S., et al. 2020, A review of extended reality (xr) technologies for manufacturing training. Technologies, 8(4), 77

Impey, C. & Danehy, A., 2022, CAPjournal, No. 31, 28-36, Exploring the Frontiers of Space in 3D: Immersive Virtual Research & Reality for Astronomy Outreach

Kersting, Bondell, J., & Steier, R., Reflecting on design principles in the context of Virtual Reality learning experiences in astronomy and science education. Universe, 7. https://doi. org/10.3390/ECU2021-09264, 2021

Leonardi, L., Daricello, L., & Giacomini, L., Learning astronomy through Augmented Reality: EduINAF resources to enhance students' motivation and understanding, Europlanet Science Congress, doi.org/10.5194/epsc2021-530, 2021

Orlando, S., Pillitteri, I., Bocchino, F., Daricello, L., Leonardi, L., 3DMAP-VR, A Project to Visualize Three-dimensional Models of Astrophysical Phenomena in Virtual Reality, RN AAS Volume 3, N.11, 2019

Rometsch, F.A.A.S.D.T., et al. 2022, Design and evaluation of an Augmented Reality tool for future human space exploration aided by

an Internet of Things architecture. Advances in Space Research

Xie, B., et al., A review on virtual reality skill training applications. Frontiers in Virtual Reality, 2, 645153, 2021

Wang, M.,et al., Augmented reality in education and training: pedagogical approaches and illustrative case studies, J Ambient Intell Human Comput 9, 1391–1402, https://doi.org/10.1007/s12652-017-0547-8, 2018

Zanazzi, A., Daricello, L., Leonardi, L., Di Benedetto, C., & Tuscano, M. L., 2021. Attracting public interest in astronomy through art and cultural heritage, European Planetary Science Congress 2021, online, 13–24 Sep 2021, EPSC2021-740, https://doi.org/10.5194/epsc2021-740.

Zheng, J. M.,et al., Virtual reality in IEEE Potentials, vol. 17, no. 2, pp. 20-23, doi: 10.1109/45.666641, 1998