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Virtual and Augmented Reality in Education Technology

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Abstract. In recent years, science educators have started exploring the huge potential of Virtual and Augmented Reality as learning tools. This article presents some examples of their implementation and analyzes features such as mobile multimedia education, also through literacy, the ethical aspects of e-learning in educational institutions, and the effect of technology on student learning. This overview of recent projects, developed by the National Institute for Astrophysics in Italy and by ReMedia Group and ATG Europe in collaboration with the European Space Agency, illustrate possible techniques and strategies to empower students' creativity and their critical sense with the use of new technologies like virtual and augmented reality.

Key words. e-learning, virtual reality, augmented reality, soft skills, digital environment, data visualization, digital twin

1. Introduction

Whereas Virtual Reality (VR) and Augmented Reality (AR) may be considered too futuristic to become a concrete part of education (Daricello et al. ((2020)), research indicates how adopting these tools encourages students' involvement and fosters deeper understanding, by making learning interactive and more experiential (Ibáñez & Delgado-Kloos (2017); Southgate et al. (2019)). Through the blending of interactive digital elements, such as visual overlays or other sensory projections, students can explore in-depth real-world environments, experiments and laboratories, suggesting a constructive impact on school performance (Potkonjak et al. (2016)).

Research also shows that an effective way to introduce scientific disciplines, such as astronomy or mathematics, at school is to present the topics on which research is being done right now, on which hypotheses, tests, and errors are being made (Levrini & Fantini (2013)), introducing the scientific process rather than transmitting content and knowledge. In this framework, this article presents a series of technology-enhanced educational activities that are based on current astronomy and space science research and are also “hands-on”. For example, students can study the characteristics of a planet or a star and then use the newly-gained expertise to start using the same tool employed in the classroom, to create something new. Consequently, the fil rouge linking the contributions discussed here is the idea of transforming the classroom into a digital playground where the subjects are represented by entertaining attractions. This overview included innovative applications to support teaching, training and scientific dissemination created by ATG Europe, and an e-learning platform developed by ReMedia Italia, using virtual and augmented reality applications, accessible through a computer or a smartphone, to provide support to students and teachers of the secondary schools. We also illustrate a number of educational activities developed by researchers at INAF the Italian National Institute for Astrophysics created using tools such as CoSpaces, Frame VR, Zapworks and interactive, web-based 3D visualizations of astronomical data.

2. Augmented Reality and Virtual Reality in holistic learning processes

Learning is a very complex and multifaceted process. Several characteristics distinguish the information learned or memorized, such as sounds, colours, and images, about different brain areas and functions. Over the past fifty years, psychologists and educational researchers, building on the pioneering work of Jean Piaget, have come to understand that learning is not simply a matter of transmitting the information. Teachers must do more than pour information into students’ heads. Instead, learning is an active process in which people construct new knowledge of the world around them through active exploration, experimentation, discussion and reflection. Learning must fully involve all aspects of the individual: mind, body and spirit. The principle underlying these theories is that an individual learns more effectively when all components are solicited to cooperate in an integrated manner. In other words, educating the whole person is more effective than educating individual parts. In particular, the Holistic learning approach presents learning as an interaction between four distinct ways of being: feeling, imagination, thought and action. Thanks to its harmonic vision of integration between the various elements such as multisensorial, multimedia, cognitive ergonomics, information technology and neurosciences, the holistic approach have become a unique tool that allows us to recognise and enhance the human being in all its parts. This new or renewed vision of the elements that underlie the holistic learning process has also received a substantial boost, thanks to the possibility of “increasing” these processes through Virtual Reality and Augmented Reality technologies. These technologies make it possible to translate educational or training activities, in the case of adults, onto a metaphysical or digital level. We are talking about a learning space, i.e. a digital, non-physical place where learning processes occur. In this digital space, AR and VR allow for the creation of educational sets in which it is possible to add audio/visual, interactive and playful elements that empower acceleration (learning efficiency) and improvement (learning effectiveness) of individual learning levels. Virtual and augmented reality grant to include logic, tools and approaches typical of games and gamification in the educational path. The classroom or the study environment is transformed into a playful, immersive, and stimulating area, that places the student in an emotional learning context in which motivation, attention and memory are strongly stimulated and increased. The considerations can be applied in the Space EduPark (see Figure 1) project by ReMedia Group. This is the first e-learning ecosystem designed and developed specifically for the school world (Leonardi (2022c)). The student accesses a gamified environment which consists of a virtual thematic playground to choose courses/attractions distributed on the space park’s various planets. Each course/attraction is therefore presented as an educational game (serious game) and consists of educational pills (lessons) and games

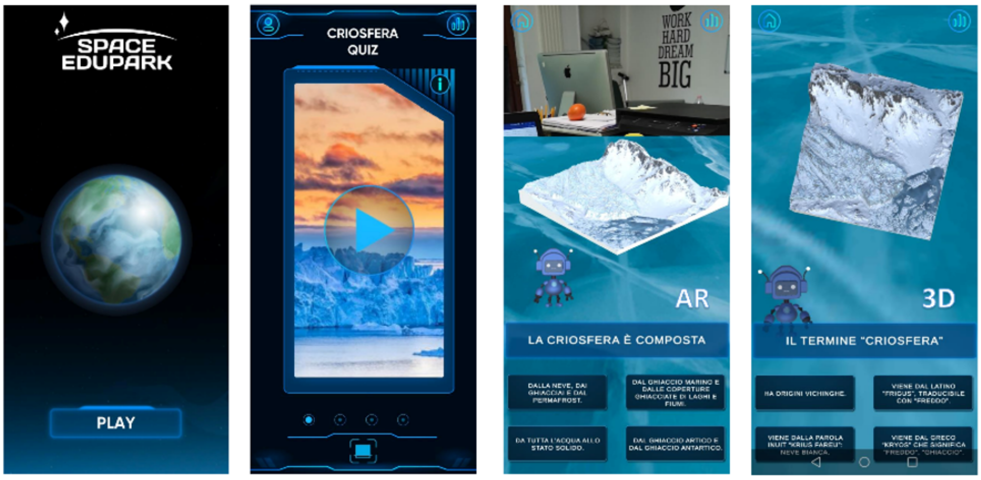

Fig. 1. Activities from the level "Terra!" (Back to Earth) of the Space EduPark application. Credits: Esa/ArMarket.

that aim to train specific soft skills. The class can be delivered: on the interactive e-learning platform Space EduPark and rich in multimedia content (from PC and mobile); through a mobile app connected to the platform to access educational experiences in Augmented Reality or Virtual Reality. The first results of using Space EduPark in schools have shown extraordinary results both in the speed and in the quality of learning by students.

3. A cosmic education: examples of "expanding" learning using Information Communication Technology (ICT)

The most recent outreach and education projects of INAF National Institute of Astrophysics, Astronomical Observatory of Palermo, are characterized by the use of innovative technologies such as Augmented Reality and Virtual Reality which are suited to communicate astrophysical research, in an effective and engaging way, to students and the general public (Leonardi et al. (2021)). In particular, to fascinate the "digital natives" and introduce them to the discovery of the universe, we have added unexpected points of view of astronomical phenomena, forcings the students to interact (Leonardi (2022a)). Augmented reality offers the possibility to "enhance" an environment, in which reality and virtual objects coexist without the need for total immersion. Instead, virtual reality creates a "different" environment, produced and managed by software and in which the user is estranged from his surroundings. The use of these two technologies is beneficial to teach subjects such as physics and astronomy, where it is necessary to explain abstract concepts and innovative visual modes through commonly used devices such as smartphones and tablets. Our activities are planned to take into account all the elements that trigger the learning process: the emotional involvement, the motivation to learn, the attention and the memory. So the keys to the whole system of our educational doings are games and realistic simulations. The game emotionally immerses students in what they are doing, stimulating their level of attention and unconscious memorization, observing something that is impossible to see with the present scientific instrumentation (Leonardi (2022b)). As an example, teachers can use holograms to show the interaction between a planet and its star, or a 3D model made using actual data coming from space and captured by the camera of a spacecraft (Orlando et al. (2019)). These interactive activities enable students not only to learn about exoplanets, stars and planet formation, but they can recreate a new project and develop their own hologram following a tutorial that we produced and published on our websites and social media (see Figure 2).

Another of the activities developed in this framework is offered through CoSpaces[1], a mixed reality web-based application that allows users to produce and engage with interactive media content, and MERGE Cube[2], a cube that allows people to hold a virtual simulation in their hand. By using these tools, we remixed an activity about the Solar System (see Figure 3) to introduce students to deeply understanding of the formation and evolution of our "planetary home". As for the holograms, students can use the same tool not only to explore the simulation with a computer or through a smartphone or tablet, using virtual and augmented reality, but they can also learn how to build a virtual reality environment in which they can develop their own interactive content in augmented reality.

Another tool that proved particularly useful to communicate science and develop immersive astronomical experiences is Frame VR[3], considered "the easiest way to enter and create the metaverse". It is possible to use the web-based application for team collaboration, social events, teaching and education, to create virtual museums, digital twins and much more. This tool was used to realize the Museum of Astronomical Models (MuMAs) (see Figure 4), an open space museum where the most energetic phenomena of the universe are exhibited just like statues or paintings, with their own labels and insights. Students can visit the museum, using an avatar they can personalize, and communicate with other visitors through chat or a microphone, while researchers can display their work and discuss it with guests.

[1] https://edu.cospaces.io/
[2] https://mergeedu.com/cube?cr=3517
[3] https://learn.framevr.io/

4. Bringing stars – and big numbers – into the classroom with 3D web-based visualizations of astronomical data)

While augmented and virtual reality offer multiple opportunities for science education, they are not always available or readily accessible to all school settings. Interactive, web-based interfaces provide an alternative, requiring only a web browser and an internet connection (Salimpour et al. (2021)). This section presents a lesson plan developed as part of the National Institute for Astrophysics educational effort, aimed at secondary school students and employing two web-based data visualizations developed by the European Space Agency (ESA) and Tulp Interactive to present basic concepts in astronomy while playing with real scientific data.

Astronomy is the realm of big numbers (Miller & Brewer (2010)). The Milky Way – the galaxy where the Sun, our own star, lives – contains hundreds of billions of stars yet it is only one among billions of galaxies in the Universe. Bringing the cosmos into the classroom through an interactive visualization tool provides an opportunity to engage students not only with phenomena that involve planets, stars and galaxies but also with the broadest range of scales available to human knowledge, enabling them to develop a sense of scale and start thinking in terms of orders of magnitude (Jones & Taylor (2009)). Star Mapper[4] is a 3D visualization of data from ESA's Hipparcos satellite (Perryman (1989)), which charted over 100,000 stars. Teachers can use it to explain the concept of apparent magnitude, showing the changing amount of stars visible to the unaided eye in different (urban, rural) settings and to ground- or space-based telescopes. The 3D distribution of stars within constellations can be demonstrated by letting students fly through the stars, grasping stellar distances and the concept of absolute magnitude (see Figure 5). Students can also explore stellar motions: millions of years into the past or future, the patterns of stars we are used to

[4] https://sci.esa.int/star_{}mapper/

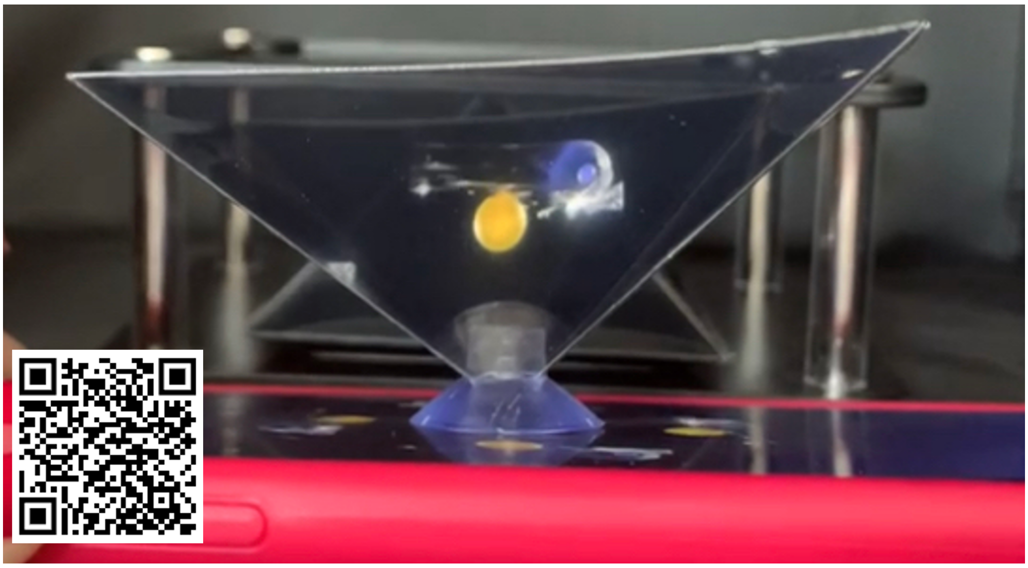

Fig. 2. A holographic representation of the interaction between a planet and its host star. Credits: INAF, OAPa

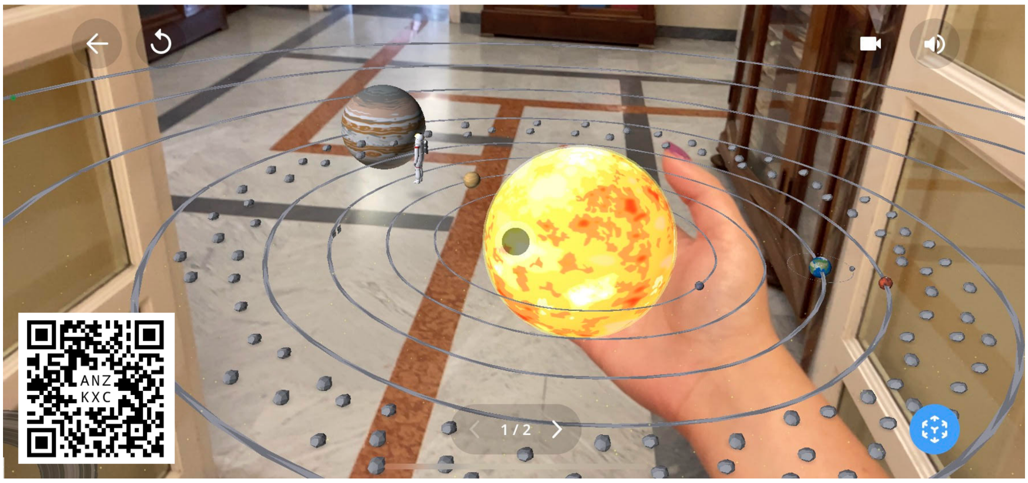

Fig. 3. The Solar system in augmented reality with CoSpaces. Credits: INAF, OAPa

will disappear, giving rise to new shapes, while only a few actual groupings of stars – stellar clusters – remain together.

Gaia's Stellar Family Portrait[5] features data from ESA's Gaia satellite (Gaia Collaboration, (2016)), scanning almost two billion stars to create the most precise 3D map of the Milky Way. Via the technique of scrolly-telling, teachers can demonstrate the huge size of this dataset and explore the distance, brightness and colour of star families (clusters) with actual data. This tool enables students to build stepwise the Hertzsprung-Russell diagram, a graph used

[5] `https://sci.esa.int/gaia-stellar-family-portrait/`

Fig. 4. The hall of the MuMAs. Credits: INAF, OAPa

by astronomers to study the evolution of stars (see Figure 6). Both applications can be combined into a 45-50 minute lesson plan, as a recap of basic concepts at the end of an introductory astronomy course; alternatively, individual concepts and the corresponding interactive visualizations can be incorporated into different lessons, as the various concepts are introduced. Preliminary tests conducted in seven 9-th grade classes at three high schools in Italy indicate the engaging power of these interactive, 3D visualizations to effectively convey complex concepts involving huge numbers, distances and timescales.

5. Applications of Virtual Reality to support teaching, engineering training and dissemination of space science

A critical step in the 3D visualization of complex technological systems and their functioning is the optimization of complex 3D models (often extremely detailed CAD files) for rendering purposes that guarantee a faithful representation of the original system while allowing the most effective and pleasant (high frame rate) interaction in real-time experience (XR). ATG Europe[6] (through its ATG MediaLab and ATG VirtualLab) has decades of experience in this domain, both in immersive (AR/VR) and conventional (still images and animations) environments. Immersive environments allow users to submerge into environments and interact with systems that could normally be unreachable (e.g. the surface of the moon or mars or again the tokamak of a nuclear fusion reactor), or present a high threshold for accessing them (e.g. the integration process of a satellite within a cleanroom, which requires an engineering degree ad years of experience). Once these environments and systems are available through immersive technologies, it is possible to allow users to interact with them in the same way in which they would experience them in real life, adding to the standard educational methods (teaching and learning) the (virtual) physical hands-on experience that is part of humans' natural way to experience and assimilate. Throughout the years, ATG Europe implemented solutions[7] that allow primary school students to learn about, and

[6] `https://www.atg-europe.com/`
[7] `https://youtu.be/U8nRbh6iV7Q`

interact with, space systems (satellites, rovers, etc.), visitors of musea to navigate the cosmos and visualize data we received from scientific missions of the European Space Agency, and aerospace engineers to explore and interact with designs of yet-to-be manufactured spacecraft as they already had a prototype in front of them. While our civilization is not new to the creation of simulative environments and mock-ups that allow the physical representation of real-life assets, a hardware copy presents high costs for realization, scarce flexibility in case of changes to the to-be-represented items, and reduced portability, often making it impossible to access the simulation without travelling to specific locations.

6. Pathways for Transversal Skills and Orientation as support for training and employment: tools and results during the pandemic

The Aprilamente method consists of conceptually nullifying the differences between all the technologies and methodologies that make up integrated systems (Sandri, Mancini et al., this volume). Since 2018 it has also been included in the Pathways for Transversal Skills and Orientation (PCTO) by the World Wide Laboratories of INAF in Naples. The application of PCTO is limited to the last three years of high school for about 5% of the time and represents an opportunity to be exploited in order to start an evolutionary path of teaching. In fact, it is now experimentally recognized that training based on experimentation and cross-curricular approach enables surprising results, consequently reducing the gap between training and work and bringing both educational and psychological benefits to students as well as making the country more competitive. However, these aspects will be discussed and explored in more detail in other contexts because they also involve considerations related to teacher training and school organization. In order to enable relevant results, PCTOs should always be conducted in presence, carrying out experimental programs thanks to the technologies available today. Unfortunately, the Covid-19 pandemic prevented classroom lessons from the end of 2019 to the first half of 2022, and lessons that had begun in presence were suddenly converted to remote, leading to a destabilization of the courses and the need to quickly reschedule activities by identifying alternative solutions that would ensure the effectiveness of cross-training and still stimulate students in the search for their aptitudes. The Aprilamente course involves practical projects of technologically advanced devices, which also require the preparation of technical documentation that is usually produced during the last year of the course. The author's chosen idea to mitigate the damage caused by the pandemic was to enable the use of augmented reality through the use of simple and effective tools[8], such as Zapworks and Zappar, not only to prepare outputs on smartphones and tablets of the topics discussed during the lectures such as the space economy, innovative startups, intellectual property protection, issues in the field of sustainable mobility and energy transition, but above all to provide students with simple and very useful tools for preparing technical and informative documentation for the advanced projects to be carried out during the course.

7. Conclusions

We presented different applications of AR, VR and technology-enhanced tools in the framework of science education. From the enthusiastic feedback received, especially from the teachers, in favour of introducing these and more experiential and immersive technologies to help students understand astrophysical phenomena, is obvious the great potential of these tools in the field of teaching and dissemination of science. Augmented reality and virtual reality activate the multisensory, emotional, and immersive participation of the students, favouring the understanding of content and improving mnemonic skills. Moreover, the self-management of the training by the student improves the effectiveness of the educational path.

[8] `https://www.dariomancini.it/augmented-reality.html`

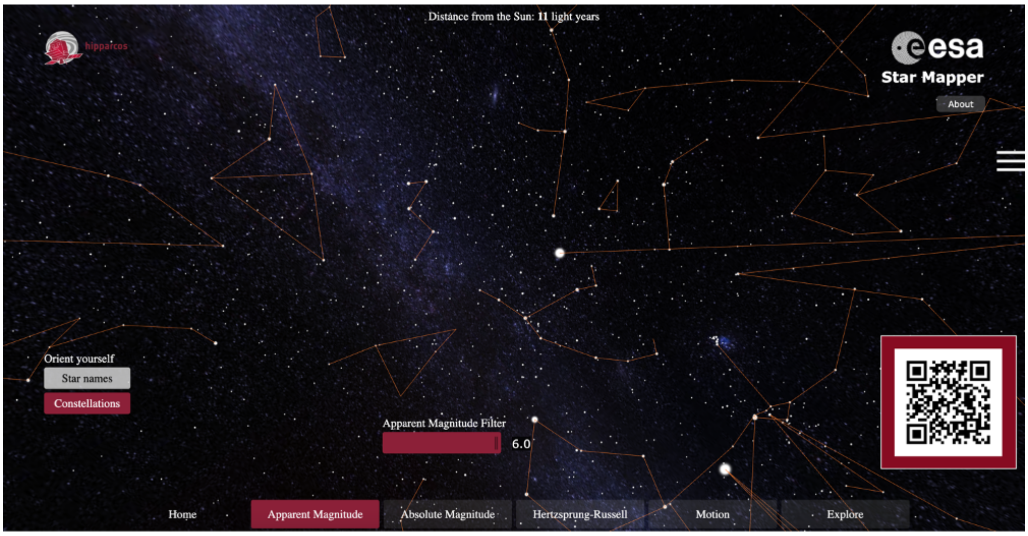

Fig. 5. Constellations and stellar distances displayed within the Star Mapper. Credits: ESA

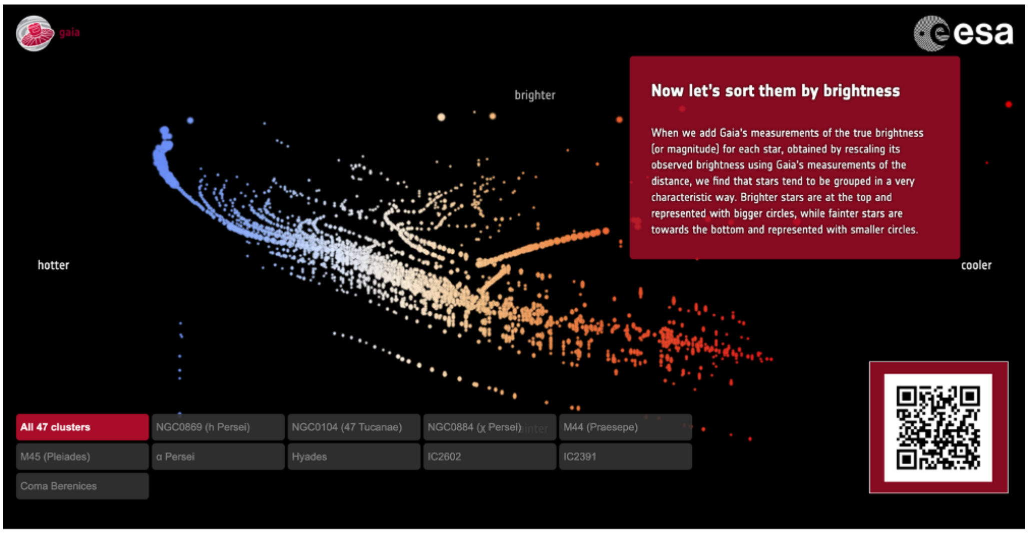

Fig. 6. The Hertzsprung-Russell diagram displayed within Gaia's Stellar Family Portrait. Credits: ESA

Acknowledgements. Star Mapper and Gaia's Family Portrait are custom-made 3D data visualisations created using web technology (HTML/Javascript/CSS) by data experience designer Jan Willem Tulp (Tulp Interactive) in collaboration with ESA's science communication and Gaia mission teams. The lesson plan was tested in 2022 with 9-th grade students of Liceo Scientifico G. Da Procida and Liceo Classico T. Tasso, Salerno and Liceo Classico Quinto Orazio Flacco, Bari with the support of teachers Maria Pontrandolfi, Marina Salerni, Raffaella Ucciero and Emilia Wanderlingh. LL aknowledges the support of the PRIN INAF "Virtual reality and augmented reality for science, education and outreach".

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