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Innovation in teaching Astronomy and Space Exploration for Improved Learning Experiences

Methodologies, case studies and best practices

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Abstract. Astronomy in education sparks innovation, blending technology and understanding of natural phenomena. It encourages problem solving, critical thinking, and cultural appreciation. It promotes environmental awareness and global citizenship, emphasizing sustainable practices. This article explores effective methodologies and resources for inclusive astronomy education, from activity design to assessment, with the aim of integrating these topics into learning environments. It concludes by addressing future challenges in advancing educational innovation through astronomy.

Key words. Astronomy activities; education and outreach

1. Introduction

Science and technology (S&T) are the basis of multiple individual and collective decisions, relating to, for example, health, climate change, energy and food security, to name but a few Davies & Horst (2016). For this reason, people need to have a certain degree of scientific literacy in order to understand S&T topics and participate in dialogue and decision-making processes with a social impact (Haywood & Besley 2014).Astronomy and space sciences are in a good position when it comes to addressing these concerns. The integration of astronomy and space exploration into education has been common practice for many years and for various reasons, either as a stand-alone subject or through specific related themes that are linked to other more established science subjects in the educational curriculum (Salimpour et al. 2021). In addition, astronomy and space exploration topics are a constant presence and enjoy great popularity on social media channels.

Some astronomy topics and themes are present in the curriculum from an early age, such as the seasons, the succession of days and nights, and the phases of the moon. Other topics, however, are not as evident and appear alongside more complex subjects that help students understand natural phenomena such as eclipses, tides, the application of the laws of physics related to orbital movements and Kepler's laws or relativistic corrections. All these subjects foster a deeper appreciation of Earth's place in the solar system and the cosmos (Salimpour et al. 2021). Observing the sky, whether through an optical instrument, a computer, or the naked eye, is an act associated with great admiration for its numerous mysteries, unanswered riddles, and the vastness of the universe, fostering scientific curiosity about celestial bodies, phenomena and the unknown, encouraging students to ask fundamental questions about our place in the universe, and stimulating critical thinking (Dang & Russo 2015; Christensen & Russo 2007).

Furthermore, astronomy has a cultural significance throughout the world, contributing to the stories, calendars, myths, and beliefs of various civilisations. This makes it possible to establish a link with cultural and historical manifestations, facilitating their appreciation and contextualisation in each community, valuing as such the historical and cultural diversity that our knowledge should embrace. Designing an inclusive and culturally relevant curriculum that represents diverse perspectives on astronomy and space exploration is an opportunity not to be missed. Indeed, by intentionally designing educational initiatives that are inclusive and accessible to diverse populations, astronomy and space exploration can serve as powerful tools to inspire, educate and empower individuals from all backgrounds, including women and other traditionally underrepresented groups in science.

Therefore, these unique characteristics have proven useful for several purposes, such as promoting scientific literacy and public understanding of science, and as a gateway to various STEM subjects (Science, Technology, Engineering and Maths), with potential to reduce differences between gender, ethnicity and cultural capital (Anjos et al. 2018; Archer et al. 2012; Sjøberg & Schreiner 2010). The multidisciplinary nature of the field can inspire students to pursue careers in areas such as aerospace engineering, robotics and astrophysics, among others, which are demanding areas driven by technological advances that require highly qualified personnel. Besides, it addresses many of the pressing challenges of today's world (climate change, energy, etc.) and is calling people to participate (for instance through citizen science projects such as the International Astronomical Search Collaboration (IASC), Globe at Night and Zooniverse[1].

Over the last few years, various methodologies and informal learning activities in astronomy and space sciences have been developed in collaboration with schools, science centers, universities and research centres at the service of the educational community, with the aim of providing innovative methodologies and experiences. Most of these activities are developed by communities of practice with links to the fields of research, education, and scientific communication, aware of the need to develop high-quality initiatives that are both scientifically rigorous but also fun and engaging (Anjos et al. 2021; Dang & Russo 2015).

Those who communicate science to, with and for the public need to have the knowledge and specific skills to engage and communicate effectively in a multicultural environment, in order to understand the norms, values, expectations, and conventions related to S&T (Anjos et al. 2018).

Many of these experiences have materialised into concrete and well-tested projects. In the following chapters, we will discuss these methods and projects in more detail, presenting its benefits and possible paths for innovation and creativity in the field of astronomy and space science to fulfil the goals of enriching students' learning experiences by fostering curiosity and inspiring future explorers.

2. Innovative Teaching Approaches for Improved Learning Experiences

Incorporating astronomy and space exploration into teaching enriches students' learning experiences by fostering curiosity, creativity, promoting critical thinking, fuelling scientific lit-

[1] For more about IASC, please visit `https://globeatnight.org/`; about Zooniverse, please visit `https://www.zooniverse.org`, (retrieved on 11.12.2023)

eracy and inspiring future innovators and explorers. These not only contribute to academic growth, but they also mould perspectives, encourage innovation and prepare current and future citizens for the challenges of a constantly evolving world.

Given all the above-mentioned characteristics of astronomy, there are well-tested methodologies that are perfectly suited to the field of education and that have been useful in developing astronomy activities in a practical and reflective way, using a variety of technologies. These include the following methodologies, good practices and resources, which we have chosen to highlight in this article, thus creating an opportunity for reflection around these and other innovative astronomy teaching practices.

2.1. Methodologies, Case Studies and Best Practices

Whether associated with a consortium or developed individually, there are a number of educational activities that have proven to be effective in facilitating learning about astronomy and engaging young people with science.

Using a variety of methodologies, such as Inquiry-Based Learning (IBL) Aparicio-Ting et al. (2019); Brumann et al. (2022), Design Thinking in education Melles et al. (2015), Universal Design for Learning Guidelines (UDL)[2], Storytelling, Flipped Classroom, Role Playing, Concept Mapping, Game-Based Learning (GBL) and AI (Artificial Intelligence)-Based Learning, just to mention a few, these case studies make use of hands-on activities, simulations, and observations that engage students actively, facilitating experiential learning and deeper understanding of scientific concepts, impacting their learning outcomes.

An overview of these case studies is presented below.

[2] For more about UDL, please visit `https://udlguidelines.cast.org/`, (retrieved in 11.12.2023)

Fig. 1. Astronomine includes a dedicated Minecraft world to introduce many topics of astronomy to students, such as the seasons, the solar system, tides, gravity, moon phases, etc., using the popular video game Minecraft

Case Study 1 - Astronomine

The main aim of AstronoMine [3] is to promote astronomy in schools through Game-Based Learning, improving the quality of education in STEM fields and strengthening teachers' digital skills. The project has produced a comprehensive handbook to help teachers introduce the topic of astronomy into their classrooms and a dedicated Minecraft world that introduces many astronomy topics to students using Minecraft.

Game-Based Learning (GBL) is an educational approach that uses games to facilitate learning and improve understanding of concepts. It incorporates elements of play, interactivity, competition and problem-solving into the learning process (Plass et al. 2015). The aim of GBL is to make learning more engaging, immersive and enjoyable for students. Developing or using educational games centred on astronomy can simulate space exploration, and a deeper understanding of celestial bodies or the formation of planets. These game-based activities aim to teach fundamental astronomical concepts while being engaging and interactive for students.

Case Study 2 - Dome

Based on a hands-on approach methodology, D.O.M.E. (Design your Own Multimedia

[3] `https://astronomine.erasmusplus.website/`, (retrieved on 11.12.2023)

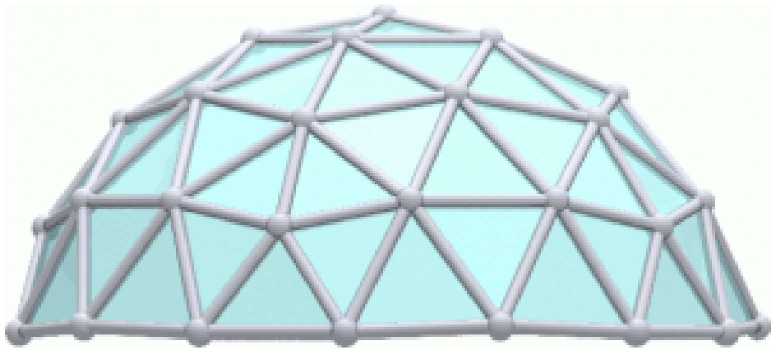

Fig. 2. In the dome project website it is possible to find an Icosahedron Dome Calculator. Adapted from Rene K. Mueller

learning Environment)[4] is designed for teaching educators in the disciplines of Science, Technology, Engineering, Arts and Mathematics (STEAM), aiming to bring an immersive practical experience that targets students from all years of schooling. Students are invited to become scientists, engineers and storytellers in a motivating experience that includes building a low-cost (cardboard) planetarium and also developing presentations for sessions involving the local community, allowing them to benefit from the planetarium and its associated resources.

Interactive and hands-on activities significantly enhance student engagement and understanding of complex astronomical concepts (Smith et al. 2005, 2011). Hands-on activities such as constructing models of a planetarium dome and models of celestial objects (solar system models, planet models) engage tactile and visual learning, aiding comprehension of scale and structure.

Case Study 3 - CliC-PoLiT

CliC-PoLiT[5] aims to engage students and the society in environmental and climate change activities to raise awareness and strengthen responsible citizenship. Incorporating the terms of climate change, urban sustainability, and light pollution into the curriculum requires systemic thinking and interdisciplinary approaches, demanding in parallel pedagogical innovations that provide interactive, experiential, transformative, and real-world learning.

By conducting experiments, through hands-on activities or using astronomy software and telescopes, students gain first-hand experience, facilitating a deeper understanding of astronomical concepts, allowing students to actively participate in experiments, observations, and simulations related to light pollution and climate change.

These activities are relevant in a way that pupils see how scientific concepts connect to their daily lives, interests, or future careers, and they become more likely to be interested and motivated to learn. By demonstrating the relevance of science, students understand its practical application in solving real-world problems. This can range from environmental issues, health, technology, to everyday phenomena. Many global challenges, such as climate change, energy resources, and public health, require scientific knowledge and innovation. Making science relevant in education can prepare future generations to tackle these challenges effectively and prepare them for societal responsibilities.

[4] `https://dome.nuclio.org/`, (retrieved on 11.12.2023)

[5] `https://clicpolit.eu/`, (retrieved on 11.12.2023)

Case Study 4 - Design-CT

The Design-CT[6] project offers teachers of all educational levels and digital competences profiles the opportunity to become creators and designers of their own digital and blended learning lessons. Through this learning platform, the educational community has access to tools that facilitate learning and empower students in an inclusive way. Most of the activities and learning scenarios use student-centred methodologies and are provided with simple steps to facilitate their implementation in class. They were co-created in partnership with the education community, using a creation tool with 60 pedagogical templates that include example lessons, tool recommendations, and guidelines. It includes AI functionalities to support content creation, providing automated designs, translations into more than 70 languages using text-to-speech technology, enhancing the text and generating a series of interactive activities.

There are selected examples on the Design-CT ecosystem that make use of several innovative methodologies to teach astronomy topics. Those are, for instance:

- The Moon has many faces but shows only one face [7]
- What if the Moon disappeared [8]
- The solar system [9]
- Our journey through the Milky way [10]

These resources were based on Inquiry-Based Learning and Flipped Classroom methodologies. IBL is a student-centred pedagogical approach that encourages learners to ask questions, explore, and investigate topics independently. When applied to astronomy education, it can be highly effective in fostering a deeper engagement of students. By observing natural phenomena, students begin to ask fundamental questions about celestial bodies and the universe. Then, learners are encouraged to seek answers through scientific inquiry, thus replicating the scientific method (Pearson 2001; Pearson et al. 2010; Smith 2015). These questions may be motivated by their personal interests and curiosity, through self-driven research and investigation, promoting a deeper understanding of the cosmos. Flipped Classroom is an instructional strategy that reverses the traditional learning environment. Instead of students passively receiving information in the classroom and doing homework at home, the Flipped Classroom requires students to engage with instructional content outside of class (often through videos, readings, or online modules) and then use class time for active learning activities, discussions, and application of concepts.

Case Study 5 - Citizen Science Projects: IASC

Production of science in schools is possible through citizen science projects such as the International Astronomical Search Collaboration [11]. IASC is a citizen science programme focused on research into small bodies in the solar system. The main aim is to empower educators and, as a natural result, encourage them to take the project into the classroom. As a consequence, students can really make original discoveries, using real data, and get excited about science and astronomy. The programme can be easily incorporated into the formal educational environment and fit certain curriculum needs. IASC is a tool for teachers and relies on the teacher to integrate it into their classroom in the way they feel it best fits their curriculum.

Using these innovative methodologies and resources, educators can create engaging and immersive learning experiences in astronomy and space exploration, catering to diverse

[6] `https://design-ct.eu`, (retrieved on 11.12.2023)

[7] Design-CT project. IMC Express (retrieved on 11.12.2023).

[8] Design-CT project. IMC Express (retrieved on 11.12.2023).

[9] Design-CT project. IMC Express (retrieved on 11.12.2023).

[10] Design-CT project. IMC Express (retrieved on 11.12.2023).

[11] `http://iasc.cosmosearch.org/`, (retrieved on 11.12.2023)

learning styles, and fostering a deeper understanding and appreciation of the cosmos among students.

3. Practical Considerations for Addressing Astronomy Topics in Education to Improve Learning Experiences

First of all, it must be assumed that developing innovative activities and practices for teaching astronomy topics and concepts integrated into education is a priority. It has been well argued how using astronomy in education serves a variety of purposes, from inspiring students towards STEM areas in an inclusive way, to developing critical thinking that empowers citizens to act and exercise global citizenship. Education systems are bureaucratic, which means that scientific discoveries take a long time to reach the curriculum in a smooth and rigorous way. On the other hand, advances in science reach the media quickly and are not always understood in the best way by the educational community and people in general (Brossard & Scheufele 2013; Howell & Brossard 2021; Scheufele & Krause 2019).

There is a responsibility on the part of the scientists involved and professionals in informal education and communication in astronomy to translate these topics so that they are more easily understood, thus reducing the noise and misinterpretations that give rise to misconceptions. As such, an important role for the community of astronomers and astronomy educators and communicators is to forge partnerships with the educational community, developing "their main activity, directly or indirectly, in formal and informal educational settings (with pre-University students, teachers and educators)" (Anjos et al. 2021), carrying out educational activities that can be articulated with school curricula.

In addition, developing teacher training programmes so that teachers feel more able and confident to teach and pass on astronomy and space science concepts is also an important step. Supporting the educational community is, therefore, a step that should go hand in hand with developing innovative activities for teaching astronomy. It is necessary to understand the needs of each school and community, both students and teachers, and to work together to advance science, promoting scientific literacy, facilitating the understanding of decision-making processes, and the development of new technologies in the scientific field.

Therefore, to facilitate the interaction with the educational community, we present practical recommendations, such as:

1. Provide resources and materials about astronomy in multiple formats – visual, auditory, tactile, and interactive, so you may reach the most diverse audiences, ensuring that learning materials are accessible to all students, including those with disabilities. Consider videos, infographics, podcasts, tactile models, and digital simulations to cater to different learning styles. Use alt-text [12] for images, captions for videos, readable fonts, and consider the use of screen readers or text-to-speech software.
2. Incorporate diverse cultural perspectives in astronomy that value diversity and inclusivity. Highlight contributions to astronomy from various cultures and societies, making the subject matter relatable to a broader range of students. Offer multiple pathways to learning and collaborative learning to promote inclusivity by valuing diverse ideas.
3. Allow participants to explore astronomy topics through various methods: group discussions, hands-on experiments, field trips, role-playing activities, and individual research projects. Assign group projects that foster teamwork, where each participant can contribute their unique strengths and perspectives. Encourage students to reflect on their learning process, strengths, and areas for improvement, fostering a growth

[12] In this context, "alt-text" refers to alternative text, which is a brief description of an image provided within the HTML code of a webpage. Alt-text is important for accessibility purposes, as it allows individuals who are visually impaired or using screen readers to understand the content of an image that they cannot see.

mindset and a sense of inclusivity in the learning environment.

4. Provide support to the educational community. Supporting educators in addressing astronomy topics in an inclusive manner requires a multifaceted approach that includes professional development, access to resources, collaborative networks, and ongoing support systems. By investing in educators' capacity to create inclusive learning environments, we can ensure that astronomy education is accessible and engaging for all students.
5. Whenever possible, foster connections with the wider community, promoting guest speakers and organizing field trips to offer real-world experiences and broaden students' exposure to astronomy. Show how astronomy can be useful in solving concrete problems in the community and how advances in this science are used in people's daily lives.

4. Practical Considerations for Assessment

Another important problem for those developing astronomy activities for different audiences is checking the effectiveness of the resources, practices and methodologies used. To help with this task, it is important to provide additional support or enrichment materials to accommodate different learning speeds and abilities in the classroom, including various assessment methods that allow students to show their understanding in different ways.

Here are two important resources that aim to answer two major questions in the field of astronomy education: how to assess student learning in a new and positive manner and how to assess how informal astronomy education activities are contributing to science learning at school.

Assessment Tool 1 - Assess

Assessment should be used as a tool for promoting development and learning. It should accommodate students' needs and embrace and protect the richness of human diversity. Considering this, ASSESS– Empowering Teachers to Design Innovative Assessment Tools in a Digital Era[13], is a project co-funded by the Erasmus Plus Agency of the European Union that developed an assessment framework that integrates knowledge from different fields of pedagogy and psychology, with the aim to set the ground for a new mindset towards student assessment and teachers' empowerment. The project offers teachers a toolkit of digital and analogue tools to assess students in an innovative way and a digital app that aggregates these tools. Teachers find an online course that will teach them not only how to use the ASSESS tools, but also how to design and create their own innovative assessment tools.

Fig. 3. ASSESS is an Erasmus Plus best practice project that rethinks the way students are assessed

Assessment Tool 2 - Surrounded by Science

The EU-funded Surrounded by Science project[14] aims to design and develop a systematic assessment methodology that analyses the impact of out-of-school science activities. By conducting field studies and other innovative data collection methods, it evaluates the impact of specific out-of-school activities. The project draws on a digital toolbox of innovative research instruments to collect data from citizens actively participating in science-related activities. The digital toolbox includes two main apps: The Science Chaser and the Science Booster. The Science Chaser app monitor users' science-related activities and provides guidance and recommendations

[13] `https://assess.nuclio.org/`, (retrieved on 11.12.2023)

[14] `https://surroundedby.science/`, (retrieved on 11.12.2023)

Fig. 4. The Science Chaser app documents the user's scientific journey and suggests other activities, including games, videos, exhibitions, etc.

for related future activity. The Science Booster will be a self-reflection and advice tool for informal science education organisations aiming to support a more effective design of out-of-school science learning activities.

By incorporating these practical considerations from the initial design of astronomy activities into their assessment, educators can create a more integrated and inclusive learning environment where all students feel empowered to engage with astronomy topics, regardless of their background, abilities, or learning preferences.

5. Conclusions

We have argued that fostering curiosity, scientific literacy, creativity and critical thinking skills through astronomy and space exploration offers numerous benefits for education, empowering students to explore, question, and comprehend the complexities of the universe while preparing them for future academic and professional endeavours and an active global citizenship.

The methodologies, practices, and resources that we have shown cultivate critical thinking by evaluating evidence, theories, and models used to understand astronomical phenomena. Space exploration drives technological advancements, and teaching these subjects can inspire students to pursue careers in fields such as aerospace engineering, robotics, and astrophysics. Although there are opportunities to include astronomy resources in teaching in a multidisciplinary and holistic way, we found that they are not always exploited by the educational community. This may mean that there is still a long way to go to overcome the challenges encountered, namely related to:

- Training and supporting educators so that they feel more confident and capable of incorporating concepts of astronomy and space into existing curricula.
- Supporting the educational community on an ongoing and frequent basis in order to cope with the rapid advance of science and technology and ensure its integration into educational contexts, continuously and not just in isolated moments or projects.
- Valorisation of this area in education, in educational policymaking, so that it is more present in curricula, either autonomously as an area of knowledge, or with links to other related disciplines.

This could mean that greater collaboration and partnerships with various stakeholders (in education, policy-making, industry, space agencies, and research institutions) could provide resources, expertise, networking and training opportunities for educators, which could facilitate the exchange of innovative ideas in education on the one hand, and the involvement of students in science and technology projects on the other.

The continued innovation and integration of astronomy and space exploration into education cultivates a spirit of exploration and enquiry and fosters a lifelong curiosity about the universe and an appreciation of Earth's place in the cosmos, emphasising the importance of environmental sustainability and global citizenship. Space exploration encourages collaboration between nations, promotes cooperation, and global awareness in education, and pushes the boundaries of human knowledge, driving scientific progress and innovation. Astronomy has worldwide cultural significance, integrating diverse cultural perspectives and histories into education. Understanding the history of space exploration shows human achievements, failures, and milestones, inspiring future generations to continue exploring and innovating. We have seen that it addresses critical global challenges such as climate change, resource management, and sustainability, offering potential solutions and applications applicable to Earth. For these reasons, it is necessary to continue supporting the efforts of all those who bring this innovation to the educational community.

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