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The ‘Universe in a Box’: a hands-on activity to introduce primary school students to cosmology

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Abstract
Physics Education Research shows that active learning and interdisciplinary strategies can enhance students’ engagement in physics. In primary school, the implementation of active learning pedagogies such as Inquiry-Based Science Education aims to encourage students’ autonomy and participation in their learning process. Indeed, active learning promotes pupils’ creativity, helping them develop the skills that increasingly determine their future employability and personal development, introducing them to STEM. In this regard, stories and storytelling can help improve teaching and students’ physics learning. Telling the Universe and its history can afford this job. The Big Bang, the Cosmic Microwave Background, and the formation of stars and planets are valuable tools for introducing primary school students to physics and the scientific method while fostering their curiosity about science. Moreover, it helps the instructors monitor the development of peculiar misconceptions on these topics, preventing them from fully understanding physics phenomena. In this paper, we present an innovative

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short-term program (one session of three hours) called 'The Universe in a Box' to introduce primary school students (grades 4–5, ages 9–10) to cosmology. We illustrate our design and the educational purposes of the program and present the outcomes from its implementation in five different laboratories in Sardinia, Italy, from 2022 to 2024 (60 students involved). This work can furnish a theoretical and methodological guide for primary school teachers and instructors on integrating formal curricula with contemporary physics topics using interdisciplinary approaches, engaging their students in STEAM (STEM plus Arts).

Keywords: active learning, inquiry-based science education, storytelling, cosmology, primary school

1. Introduction

Since the dawn of time, studying the cosmos has driven humans' interest and curiosity about understanding nature. The development of mythology and cosmological models all over the centuries was to understand where we come from, who we are, and our life position in the broader picture of the world. All cultures have developed systems and models for understanding natural phenomena, and cosmological ones are of broad interest. For experts, cosmology is a science that tries to explain the origin and evolution of the Universe [1]. However, for people in general, cosmology also deals with understanding the role and meaning that human life has within the cosmos. As such, dealing with this imagination of science and preventing the emergence of wrong interpretations of cosmological phenomena since primary school is a priority for Physics education research (PER).

In a broader sense, cosmology relates to the world views held by students. For example, the 'Big Bang' metaphor used to imagine and describe the unknown, i.e., the initial state of our Universe according to the Standard Model of Cosmology is always understood as an explosion [2, 3]. However, this pictorial image is wrong, since nothing could explode when space and time did not exist yet. Preventing the development of such wrong ideas since primary school not only allows instructors to introduce students to phenomena in our Universe and their conceptions about them, but it also offers the possibility to debate about what is science and what is not, what can be measurable and what is not, thus fostering pupils' critical thinking and creativity [3–6]. It also acts as a tool to introduce students to the scientific method, providing learning experiences to engage them with fundamental questions about the universe and related investigations [7–9].

Primary school students generally have a great motivation to explore the world, showing a little scientist's attitude. However, curiosity for scientific phenomena is something different from the acquisition of structured scientific thought, which should be acquired during the in-school time they will spend for many years of their lives. In this context, a slow and progressive inquiry approach starting from the real non-idealized world of the context in which the child lives and studies can be of great help [10]. Hands-on and minds-on activities based on the Inquiry-Based Science Education (IBSE) pedagogy seem promising in this direction [11]. The IBSE methodology is widely recognized as effective in developing students' science and technology literacy, encouraging them to be directly involved in inquiry [12–14].

In this regard, mixing it with narratives and storytelling can help improve teaching and students' learning of physics [4]. Indeed, storytelling is a helpful tool in education to engage, excite, and emotionally involve students in science. It fosters a sense of wonder, enthusiasm, and interest in science. The use of nursery rhymes and poetry based on cosmological metaphors can also afford for this job. Indeed, when opportunely contextualized, metaphors are valuable tools to foster pupils' visual thinking skills, leading them to imagine the invisible world described by contemporary physics [15–17]. By integrating structures from different conceptual spaces, from our everyday life experience (the metaphor source) to something unknown and paradoxical (the metaphor target, i.e. a contemporary physics topic), we shape knowledge with new features that did not exist in the original spaces. This process is structural in physics when new knowledge is built from previous using an analogical and metaphorical conceptual understanding of phenomena [18–20].

This work focuses on using active learning and interdisciplinary strategies to introduce cosmology at primary schools and integrate this topic with formal curricula. Our research question was: How do we design an educational activity based on this framework to promote physics awareness and literacy and offer a methodology for introducing and teaching contemporary physics in class with real-life, low-cost experiments? The goal was also to develop a tool to engage pupils in hands-on activities, making them explore our Universe with inquiry.

In this paper, we address our research question by reporting on an innovative short-term program (one session of three hours) called 'The Universe in a Box' to introduce primary school students (grades 4–5). We illustrate our design and the educational purposes of the program and present the outcomes from its implementation in five different laboratories in Sardinia, Italy, from 2022 to 2024 (52 students and ten teachers involved). This work can furnish a theoretical and methodological guide for primary school teachers and instructors on integrating formal curricula with contemporary physics topics using interdisciplinary approaches, engaging their students in STEAM (STEM plus Arts).

2. Methods

We introduce an innovative approach to teaching cosmological concepts through a hands-on activity designed for primary school students, specifically targeting 4th and 5th grades (ages 9 and 10), the final two years of primary education in Italy. According to the national curriculum guidelines [21], by the end of primary school, students should acquire mathematical, scientific, and technological knowledge that enables them to analyze real-world data, assess the validity of quantitative and statistical information, and cultivate a rational approach to problem-solving. They are expected to develop critical thinking skills based on empirical evidence, while recognizing the limitations of definitive conclusions on complex issues. Furthermore, they should display curiosity, seek meaning, and demonstrate the ability to observe and interpret environments, events, phenomena, and artistic expressions. These competencies are essential for engaging with both the conceptual and practical challenges of our educational proposal.

The activity design is as a laboratory, with both hands-on and minds-on activity. It lasts three hours. Storytelling helps the instructor tell the Universe's history like a 13.7 billion years journey. Some of the main stages in the history of the Universe according to the Standard Cosmological Model [2, 22] are chosen to focus on peculiar conceptual knots in cosmology and foster students' minds-on and inquiry processes. The use of poetry and poems is also helpful to achieve this goal. Indeed, each laboratory phase starts with a poem concerning its physical contents. Poems are taken from [23], where concepts and scientific metaphors are in both Sardinian and Italian languages. The hands-on and the storytelling (minds-on) phases go in parallel throughout the laboratory. The phases of the lab and their duration are shown in table 1.

To build the box, students use low-cost materials. The instructor involves teachers in explaining which kind of material is needed (pencils, glue, scissors, tape, and cardboard). Students can bring the materials from home or use the class material. The final product is theirs. Teachers can ask them to leave it at school or bring it home. The activity of building the Universe in the box can also be led in small groups to foster cooperative learning skills.

The realization of the box involves using the template in figure 2. To cut it, scissors should be used. To close the box, glue or sticky tape can be used according to the type of paper used (e.g. thin cardboard or simple white paper). As a mandatory part of the laboratory, the zeroth phase concerns explaining the safety instructions and materials.

The physics elements to represent within the Universe are as follows: the CMB, the darkness of the Universe, stars, planets, and galaxies. These elements cover five faces of the box. Pupils can

Table 1. Laboratory phases.

Phase	Topics	Duration (minutes)	Activity
0	Materials; Safety rules	10	-Explanation of materials -Precautions and safety instructions
1	Cosmology; The Big Bang	40	- Explanation of what cosmology is and its scientific topics - Explanation of the birth of the universe according to the cosmological model - Discussion on the ‘Big Bang’ metaphor - Building of the Box
2	The Cosmic Microwave Background (CMB)	40	-Telling the history of the first 380 000 years of the universe -Discussion on the ‘primordial soup’ metaphor -Drawing the CMB inside the box
3	Stars and planet formation	60	-Telling the physics of star and planet formation; -Telling and discussing the physics of stars and black holes -Decorating the box with stars, planet, and galaxies - Closing the box
4	Final debate	40	-Students writing words, texts, feeling about the lab and physics -Recap of the activities -Discussion on students’ feelings and feedback

draw them or, using some figures printed by the instructor, attach them to one of the faces with some tape and a cotton thread. Each element corresponds to a specific cosmological stage and a specific laboratory phase.

The sixth face is left for wording and creativity. Students can write the words to summarize and describe the laboratory, briefly describe the universe and its physics along the lines of the laboratory, and express their feelings about the laboratory and physics in general. In the following, we illustrate and discuss the in-class phases of the laboratory.

2.1. First phase

The first phase of the laboratory is the ‘Big Bang’ stage. The inquiry phase starts with a stimulus question: ‘Big Bang. What comes to mind?’. During this part, the instructor should annotate all

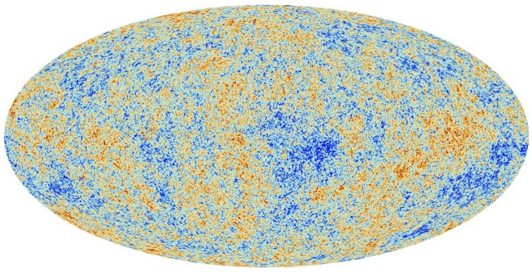

Figure 1. The CMB as measured by the planck satellite. Credits: ESA and the planck collaboration.

students’ suggestions, fostering a minds-on process on the Universe’s initial state. After collecting students’ ideas, the instructor explains what cosmologists know about the initial state of the Universe. To introduce them, s/he can use scientific poems to stimulate their curiosity, guiding them to think about the meaning of the metaphor. Then, s/he explains the ‘Big Bang’ metaphor to make pupils realize that there has been no ‘bang’ at all at the initial stage of the Universe, as far as we know from the Standard Cosmological Model [2, 22].

In the first phase, the instructor can focus on students’ conception of the ‘Big Bang’ metaphor, investigating the role of metaphors and images in building knowledge. Indeed, the existence of a ‘bang’ implies the need for a place in space and a proper time where an explosion has occurred, whereas the ‘Big Bang’ corresponds to the birth of the concepts of space and time themselves. Metaphors should be accurately explained and discussed with the class to prevent the development of misconceptions, although leading students to counterintuitive and paradoxical situations.

2.2. *Second phase*

In the second phase, the class starts building the box using the template the instructor gave. After that, the third phase introduces the CMB [24], see figure 1. In doing so, a brief recap on the Universe’s first 380 000 years of history after the Big Bang phase is made. The instructor introduces another metaphor, the ‘Primordial Soup’, corresponding to the initial state of matter and

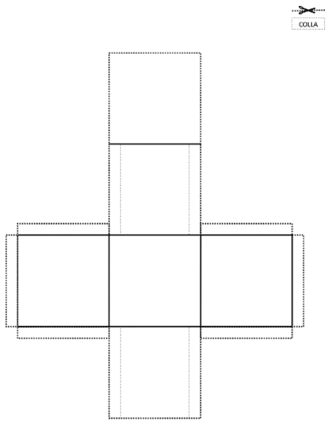

Figure 2. The project to build the box. Cut the picture along the dotted bold lines. To close the box, glue is applied in the areas limited by the dotted clear lines. External areas on the left and right should be bent and glued with the previous ones.

energy mixed in plasma. This activity introduces them to matter and its constituents and, although roughly and qualitatively, to Einstein’s Special Relativity equivalence between matter and energy (the famous formula $E = mc^2$). During this phase, the instructor also uses exhibits to explain the Universe’s accelerated expansion, trying to stimulate class curiosity and inquiry towards this phenomenon. It corresponds to the role played by the dark energy in making the Universe expand over the years, making it grow faster and faster. To explain this concept, one can use a plastic balloon with some galaxy drown on it. After inflating by blowing air in it, one can observe galaxies moving away far from each other, even if the relative distance between them does not change. This explanatory phase introduces the concept of CMB, the oldest light memory of our Universe. Indeed, while the Universe was expanding and particles and light separated, the high-energy photons (the particles of light) stopped interacting with matter (which, in turn, started forming atoms). It took 380 000 years for the light to rest alone, not interacting with matter anymore. After this period, the CMB remains the remnant of this primordial light coming from the Big Bang. After the physics explanation, students start drawing the CMB on five of the six internal faces of the box, see figures.

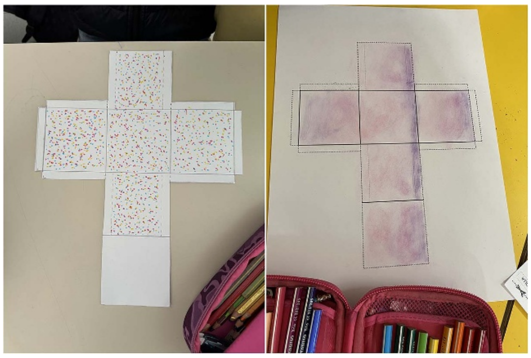

Figure 3. Two examples of CMB drawnings by students.

2.3. Third phase

The third phase concerns what happens in the Universe while it is expanding. First, the 'dark era,' e.g. when matter has not collapsed to form stars yet, is introduced. Second, the instructor introduces stars, planets, and galaxy formation.

The third phase corresponds to the third stage of the journey, placed ten billion years after the Big Bang. Concerning physics, the instructor focuses on stars and planets. S/he poses stimulus questions about what stars and planets are. The activity focuses on discovering the mechanism of light production in stars. In stars' nucleus, matter reaches the state of plasma. The gravitational field inside stars is strong enough to allow quantum particles, e.g. protons, to interact, forming deuterium. This reaction releases a large amount of thermal energy, which suddenly transforms into photons, e.g. light, traveling from the inner to the outer part of the star. After that, the instructor guides pupils in discovering the evolution of stars according to the astrophysical models. If stars have Solar masses, they start inflating due to their energy production reaching the state of a red giant. When the fuel inside them ends, they collapse to form a white dwarf. Colors refer to their external temperature. For stars with more than one Solar mass, two possible evolutions occur. At first, they start to expand, reaching the Supernova state. If they reach 1.4 Solar masses and their fuel ends (no more nuclear reactions in the core), the Supernova collapses due to its gravitational field, leading to a neutron star in its core. A neutron star is a star with an external surface made of neutrons with a diameter of ten kilometers and a density of 10^{17} kilograms per cubic meter. If they have more than 1.4 solar masses when the fuel ends, the Supernova collapses due to its gravitational field, leading to a black hole nucleus. Black holes are regions of spacetime where gravity is so intense that even light cannot escape from there. However, this is another pictorially metaphor [25] representing the idea of an obscure region of spacetime where everything falls, and objects cannot escape from there. Nevertheless, even if we cannot observe them, we can study them by the motion of stars and matter surrounding them [26, 27] or by detecting the gravitational waves produced by the merger of two black holes [28]. The storytelling phase ends by mentioning future experiments that will allow the scientific community to explore the Universe up to cosmological distances, reaching the still unknown dark era cited above. It is the case of the Einstein Telescope (ET) experiment [29, 30], a detector capable of observing the entire Universe using gravitational waves aiming to increase a factor of ten the sensitivity of previous generation detectors [31].

During this phase, the instructor shows and comments on the pictures of celestial bodies s/he is dealing with, trying to engage pupils in physics. Some examples of stimulus questions are as follows: the size of celestial bodies compared to objects around us on the Earth; how far are they from us; trying to figure out cosmological distances. Another conceptual knot concerns why the cosmo is dark even if stars emit light. This point introduces the finiteness of the speed of light and how distances are measured in cosmology. During this phase, the instructor guides pupils in measuring distances as a function of time. For example, the Sun-Earth is 8 min times the speed of light, e.g. light emitted by the Sun takes 8 min to reach the Earth. Trying to make the same exercise for bodies further away, such as other stars or galaxies, or the CMB, the instructor guides the class in discovering that by looking at a star far away from our reference frame, we are looking into the past. In this way, they should become familiar with the standard approach to cosmology.

Moreover, this discussion aims to explain why the cosmos appears dark, although the Universe has plenty of stars (about a hundred billion) and galaxies (about a hundred billion). It is too large (a length of about 10^{26} metres) for the light to cover all its extension. Thus, it appears as dark. For this reason, during the second phase, the students cover the CMB with a dark piece of tissue paper. It also shows how difficult it is to discover the content of the Universe only by using visible light.

The third phase closes with a hands-on activity involving putting planets, stars, and galaxies inside and closing the box. As described in the previous section, the instructor prepares some pictures in advance and lets pupils choose three or four to decorate their Universe in a box.

2.4. Fourth phase

During the fourth phase, students write thoughts, feelings, or brief texts about the Universe and cosmology. They are free to choose the narrative technique they prefer. The instructor collects the texts and discusses them with the class.

3. Reflections and implications

In this section, we describe the implementation of our design across five different laboratory sessions in primary schools in Sardinia, Italy. The project involved three schools from different regions of Sardinia: two located in the central area and one in the south. In two of the schools, we were requested to organize separate laboratory sessions for the two target groups: 4th and 5th grade students (ages 9–10). The schools had reached out to the Physics Department of the University of Cagliari, seeking innovative labs centered on active learning methodologies and hands-on activities. Prior to conducting the sessions, we collaborated with the teachers to discuss both the topics and the pedagogical approach. The activities were then carried out in classrooms during the students' regular curricular hours.

The student sample is detailed in table 2. All participants were from Sardinia and spoke Italian as their first language. Students from the southern region reported that they understood some Sardinian words but were unable to speak the language fluently. In one case, however, at a school located in the central region of the island, all students ($N = 22$) confirmed their fluency in spoken Sardinian. This was further corroborated by the authors, as the lab session was conducted predominantly in Sardinian, with Italian translations provided for the technical physics terminology. However, the students did not know how to write in Sardinian, which was expected. In central Sardinia, where efforts to preserve the language are more active, Sardinian remains commonly spoken across generations. In contrast, in larger towns and cities, the language is less commonly used, especially among younger people. The details of conducting the laboratory in Sardinian, along with studies on its cognitive and emotional impact on learning, will be explored in a forthcoming paper.

Table 2. Students' sample involved in the study. The 'F' stems for females and the 'M' for males.

Zone	Class	Gender	N
Center	4th	4 F; 1 M	5
Center	4th	6 F; 5 M	11
	5th	3 F; 8 M	11
South	4th	3 F; 8 M	11
	5th	9 F; 5 M	14

Ten teachers participated in the project, with two assigned to each class, serving as representatives for their respective schools. During informal discussions held during the activity, only two teachers (from the south) indicated familiarity with cosmology, having introduced basic cosmological concepts such as the Universe and its history to their 5th-grade students. These teachers had also incorporated fundamental astrophysical concepts, such as planets, stars, and galaxies, into their curriculum. However, despite this, their knowledge of the topics covered during the lab sessions appeared to be limited. When asked where they had learned about cosmology, they mentioned personal research on the internet and YouTube videos. Regarding our pedagogical approach, the two teachers stated they were familiar with active learning strategies, particularly IBSE, as this is required by their school administrator. In terms of physics, they only taught classical concepts, such as gravity and mechanics, and solely from a theoretical perspective. Practical experiments were limited to biology (e.g. DNA extraction from fruit), chemistry (e.g. pH testing of liquids), and natural sciences (e.g. plant or seed cultivation). We also observed that their schools were well-equipped with science labs and a variety of experimental tools for educational purposes. The remaining eight teachers admitted that they did not teach physics in their science classes, either theoretically or experimentally, and had not included cosmology in their curricula. Their focus was more on biology and natural sciences. Their schools were not equipped with scientific educational laboratories or apparatus. Nonetheless, all the teachers expressed interest in STEM activities and, at the conclusion of the lab sessions, requested additional interventions related to STEAM education. The teachers appreciated the use of storytelling as a means to introduce cosmology and related topics, as well as the task of designing the box. They noted that constructing the box was a creative activity for the students, encouraging both their artistic and scientific creativity. The artistic aspect was seen as closely connected to the scientific, as students were tasked with expressing their own interpretation of the universe's story through this project.

Supporting teachers in developing design practices that incorporate such approaches is a priority for researchers involved in teacher education programs. It is recognized as a challenging task, given the substantial knowledge, skills, and values required for designing and implementing inquiry-based practical work [32]. We suggested that providing supportive frameworks and interventions, such as hands-on laboratory activities, could significantly enhance teachers' understanding of science content and knowledge-building practices, thereby promoting the teaching of physics in primary schools [33, 34]. As noted in [35], incorporating the Arts into classroom practices provides a well-rounded blend of disciplines that fosters key skills and attitudes, such as creativity, critical thinking, and an innovative mindset in students. Since the quality of teaching plays a crucial role in the success of such pedagogical approaches, teachers must develop the knowledge, skills, and confidence needed to effectively implement these methods. This highlights the importance of expanding teacher development and training programs that include STEAM practices, enabling both pre-service and in-service teachers to build their expertise and experience. Such programs would enhance their ability and preparedness to teach subjects using integrated, interdisciplinary approaches [36].

Figure 4. Two complete boxes representing the universe by two students (grade 5). The small black sheets of paper create the darkness effect in their universe. On the left, the celestial bodies are the Sun and the Earth, both drawn by the student. On the right are the Earth, some planets like Saturn and Jupiter, and the Sun. The student used the pictures brought by the instructor.

Table 3. The most used words to describe the laboratory collected during the in-class activities.

Words	
Infinity	Sun
Big Bang	Milky Way
Physics	Galaxies
Nucleus	Universe
Light	Planets
Life	Gases
Stars	Funny

In figure 3, we show an example of students' artistic representations of the CMB. The final rendering of the 'Universe in a Box' by students (grade 5, 5th year at primary school, 10 years old) is in figure 4. Here, we focus on the final discussion phase. Results are in tables 3 and 4.

Concerning the hands-on activity of our laboratory, making the box fosters students' creativity. In particular, we noticed that all of them were trying to figure out and visualize the invisible phenomena discussed, especially for the CMB. About one-third of the sample exactly reproduced

Table 4. Some of the sentences wrote by students concerning the word ‘infinity’. English translation is by us.

Sentences
1. In the darkness, there is the Big Bang.
2. In every galaxy, there is an unexplored point to discover.
3. There are unexplored things in the Universe.
4. The infinity does not exist because no one knows what it is.
5. The infinity is not infinity. It stops in front of the wall of ignorance.
6. Infinity exists if one does not give up.

the image of the CMB in figure 1. Most students tried to draw their cosmic memory creatively. In-class discussion showed that the sample appreciated this creative part of the laboratory. Unfortunately, we noticed that pupils need help handling tools like scissors or glue. According to their teachers, little attention is given to hands-on activities in favor of an extensive use of smartphones in familiar contexts and classes. For this reason, students cannot often connect what they should do with proper practical action, and the instructor’s intervention is mandatory to continue with the activities.

Students appreciated the use of poems to introduce them to physics. During the debate phase, most students affirmed that poems stimulated their imagination, making them visualize the proposed phenomena. In particular, poems were in Italian and the Sardinian language and taken from a book [23] devoted to communicating high-energy contemporary physics, general relativity, and cosmology to primary school students.

Concerning the wording phases, in all of the laboratories we organized, the debate phase mainly focused on two concepts: the ‘Big Bang’ and ‘infinity’. Concerning the former, we started investigating it during the first phase of the laboratory. What emerged is that all students knew about the Big Bang. Indeed, when asked, ‘How was the universe born?’ everyone said, ‘From the Big Bang.’ However, when asked, ‘What is the Big Bang?’ they did not know the answer and rested silently. When asked, ‘What comes to your mind with the term Big Bang?’ everyone said, ‘A big explosion’. Investigating more, most of the sample imagined this Big Bang in a way very similar to Lemaitre’s hypothesis of the primeval atom [37]. Indeed, they did imagine an exploding atom that gave birth to the whole universe. The role of the instructor was to make them aware of the metaphorical meaning of the term, trying to avoid the idea of an explosion. The same happened in the history of physics, where the metaphor was only used a few decades ago [3]. When asked, ‘From where did you learn about the Big Bang?’ the answer was about documentaries on TV shows and social networks. It reveals that more educational programs devoted to contemporary physics should be implemented since primary school to prevent these misconceptions from arising.

Students related the concept of infinity to the length of the Universe. They were fascinated by this topic and wanted to know more about its shape and its content. The first idea they consider is that the Universe is infinite by definition. During the laboratory, they discovered that the visible Universe is 13.7 billion years old, corresponding to a finite length of about 10^{26} metres. On the one hand, they thought that it was impossible. On the other, they were fascinated by this change of perspective. Indeed, after this discussion, they started modulating their ideas of infinity, passing from physical and mathematical perspectives (see items 1–3 in table 3) to a sociological one (items 4–6 in table 3). Concerning mathematics, we noted that students could handle the sum, subtraction, and product between large numbers, even if they needed to properly realize their physical meaning when associated with spatial properties of bodies. For example, they thought the distances between celestial bodies to be more or less the same within the Solar system. One reason can be pictures they see in scholarly textbooks, where planets are equally far away from each other [38, 39–41].

More laboratories and training activities for primary school teachers devoted to exploring the concept of measure are needed. Students should explore the measure by hands-on activities, reasoning about the orders of magnitudes and differences between them. They should also learn the scales and distances in the Universe since primary school, training their abstraction and imagination according to the scientific method. Such kind of hands-on activities should be integrated into schools to promote active learning and the development of STEAM skills [40]. They allow students to move from conceptualizing an ideal project to designing and realizing it. Indeed, as noted in [41], incorporating the Arts into STEM education (STEAM) equips students to tackle global challenges by fostering innovation, creativity, critical thinking, effective communication, collaboration, and the creation of new knowledge. STEAM education plays a distinctive role in this regard, as the inclusion of the Arts encourages diverse problem-solving approaches and nurtures an open, subjective form of knowledge based on divergent thinking. This contrasts with the objectivity and convergent thinking traditionally associated with scientific methods [42].

4. Conclusions

In this work, we proposed a hands-on activity to promote the learning of cosmology in primary schools, specifically designed for 4th and 5th-grade students (ages 9–10). The activity was implemented five times in Sardinia, Italy. Our approach builds on previous research aimed at introducing contemporary physics topics, such as astrophysics and particle physics, to primary education, with a focus on the scientific method and the nature of science [5, 39, 43–45]. The core research question we addressed was how to design an educational activity that enhances physics awareness and literacy, while providing a methodology to introduce modern physics concepts through real-life, low-cost experiments.

To address this, we designed an educational tool called ‘The Universe in a Box’, which employs active learning strategies, specifically the IBSE methodology. The project had two main goals: first, to engage students in hands-on activities that encourage them to explore the Universe through inquiry; and second, to introduce cosmology in an interdisciplinary context, blending techniques from various disciplines to enrich the learning experience. Our educational program is structured into various learning phases that address both conceptual and practical aspects of cosmology. The conceptual component covers complex topics about the Universe, such as the Big Bang, the formation of cosmic structures and the CMB, as well as methods for measuring astrophysical distances.

Our findings are encouraging. Introducing such advanced topics through real-life, low-cost experiments allowed us to achieve our research goals. The overall student feedback was positive, with the activity engaging them in physics and promoting inquiry-based learning. Storytelling played a central role in the design, engaging students both cognitively and emotionally. The inquiry process was sparked by stimulus questions about celestial phenomena, encouraging discussion using natural language (often through metaphors) and hands-on activities. Our methodology can assist teachers in developing an integrated STEAM curriculum, blending formal science education with the history of science and the arts [40]. Such approaches are highly effective in motivating students to pursue STEM fields while also fostering essential skills like solving interdisciplinary real-world problems, critical thinking, collaboration, and creativity [46, 47].

The qualitative findings from discussions with teachers offer valuable insights into their approaches to teaching physics and highlight the need for specialized STEM and STEAM professional development programs. These programs should provide explicit opportunities for crossing disciplinary boundaries [34]. Despite the growing emphasis on interdisciplinary approaches in professional, academic, and societal contexts, STEM education remains inadequately implemented in formal curricula. It is often criticized for the disconnected teaching that reinforces rigid separations between disciplines [48].

One critical step is to re-evaluate pre-service teacher education. Teachers and teacher educators tend to focus on specific disciplines and are often not trained for the kind of interdisciplinary dialogue needed to address emerging societal challenges. This underscores the importance of offering innovative educational tools and programs to both in-service and pre-service teachers, with the research community playing a central role in this endeavor [49]. Our design is a preliminary step in this direction, focusing on introducing contemporary physics topics into the classroom.

The study, however, has some limitations that future research should address. Our analysis of students' work is purely qualitative, meaning we were unable to identify the specific cognitive factors that contribute to the effectiveness of our methodology. Conducting interviews with students or developing formative evaluation methods for assessment could provide further insights into this area. These lines of research are left for future investigations.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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Ethical statement

Informed consent to participate in the study has been obtained from participants. Any identifiable individuals participating in the study have also been aware of the intended publication. Informed consent to publish has been obtained from participants of the study. This work was carried out in accordance with the principles outlined in the journal's ethical policy and with the 'Codice etico e di comportamento' of the University of Cagliari.

Conflict of interest

There are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

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