Using storytelling to foster the teaching and learning of gravitational waves physics at high-school

M Tuveri[1,3], A Steri[2,3] and D Fadda[4]

[1] Dipartimento di Fisica, Università di Cagliari, Cittadella Universitaria, 09042 Monserrato, Italy

[2] Dipartimento di Ingegneria Meccanica, Chimica e dei Materiali, Università di Cagliari, 09123 Cagliari, Italy

[3] Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, Cittadella Universitaria, 09042 Monserrato, Italy

[4] Dipartimento di Pedagogia, Psicologia, Filosofia, Università di Cagliari, 09123 Cagliari, Italy

E-mail: `matteo.tuveri@ca.infn.it`

Abstract. Studies in Physics Education Research show that interdisciplinary approaches in education foster students' motivation, creativity, curiosity, and interest in physics. We discuss their features and potential role in bringing contemporary physics topics to high school and how to use them to integrate formal educational programs. We make an explicit example of the use of storytelling and theatrical techniques to introduce secondary school students to black holes and gravitational wave topics. The Educational Division of the Physics Department at the University of Cagliari designed the activity. Participants were 200 high-school students (17 to 19 years old) from five schools (scientific, humanities) in Sardinia. Through a research questionnaire, we measure the efficacy of using artistic tools to communicate and teach the proposed subjects. We collected 76 answers. Results show that our methodology helps introduce students to contemporary physics themes, fostering their interest and learning of such content. Students from the humanities significantly appreciated the use of poetry and artistic tools more than their scientific peers. Finally, we discuss the potentiality of our approach in orientating students towards a STEAM (STEM and Arts) career.

Keywords: informal learning; interdisciplinary; storytelling; STEAM; general relativity; gravitational waves

Submitted to: *Phys. Educ.*

1. Introduction

Offering an interdisciplinary vision of science to high school students and teachers are becoming a common learning trend (see [1, 2, 3] and refs therein). In its simplest form, interdisciplinary constitutes an appreciation of different discipline fields and the value of communicating across disciplinary boundaries to find ways to work together. As emphasized in [4], playing and learning content and methods from different disciplines bring educators and students to develop new scientific reasoning and toolkits. Learning experiences and skills acquired through the interdisciplinary application of physics fundamentals to real-world solutions make a connection between the world of research and society. To show how science is evolving and to provide new instruments to learn science and physics in an enlarged context, mixing knowledge, techniques, and methods from different disciplines should be part of science and education curricula, developing an integrated model of learning and teaching [5]. Interdisciplinary approaches in education also enhance students' engagement in physics [6].

In general, experts carry out these kinds of educational experiments in informal contexts, such as out-of-school time, and outdoor activities, science outreach labs, visits to museums, summer camps, where they keep in contact with science through different media and activities [7, 8, 9, 10]. Researches show that teaching science in informal contexts increases experience excitement, interest, and motivation to learn about phenomena in the natural and physical world, improves scientific awareness and literacy [11, 12, 13, 14, 15], bolstering motivation to learn science and physics [16, 17, 18]. It also helps them in building a "culturo-scientific thinking", that is, learning how to think scientifically and creatively, with an understanding of the evolution of the nature of science [19].

Integrating the best learning practices in informal contexts, even in formal school curricula, could benefit students' science learning, engagement, and motivation. Mixing arts and science seem very promising in this direction [6, 7]. Research results show that arts, narrative, and drama help students reflect on scientific concepts and science evolution from epistemological and historical perspectives. It promotes peer interaction at school and interaction among school, family, and society [20], also preventing students from school abandon [21]. Moreover, it helps teachers better understand students' thinking [22]. This approach involves emotional involvement to foster students' scientific imagination and creativity development, allowing personal learning styles and cognitively mediating in approaching physics (see [6] and refs therein). Moreover, when followed by minds-on activities, such as a debate, students re-elaborate what they experienced and re-propose contents in a personal way, bettering their learning process [11, 12], developing their critical thinking skills. These activities also orientate students towards a STEM career [23, 24].

To show how science is evolving and to provide new instruments to learn science and physics in an enlarged context, mixing knowledge, techniques, and methods from different disciplines should be part of science and education curricula, developing an interdisciplinary and integrated model of learning and teaching [1, 2, 3, 5, 25]. Nevertheless, sometimes secondary science teachers need help in inspiring their classes. Stories can help improve teaching and students' learning, and physics is full of stories that can afford this job. The use of narrative and stories to teach physics has some well-recognized benefits in education, presenting science in a more "coherent, memorable, and meaningful format in order to interest and engage pupils, as well as to unify the curriculum and to preserve a sense of the bigger picture" (see [26], p.121). Storytelling can be used as a stimulus to engage, excite, and emotionally involve experience from which to learn, also bettering students' capability to memorize concepts [26, 27]. Millar and Osborne [28] enlightened the role of sustaining and developing the curiosity of young people attending a science curriculum, fostering a sense of wonder, enthusiasm, and interest in science. It seems that stories could achieve this sense of wonderment, enthusiasm, and interest in science, provided they are relevant, fun, and interesting [26].

Despite experts recognizing its role in education in many contexts, particularly in science education [27, 29, 30], the introduction of storytelling in school is rare. Since storytelling has its genesis in arts, someone speculates that it is less than a rigorous pedagogical methodology to teach and learn [31]. This idea can be mediated by the fact that instructional approaches that are perceived to be subjective and less rigorous will only be adopted with cautious reservation, basically for science communication [32], not for science lessons [33]. However, as noted in [34], teaching itself is, in reality, nothing more than an evolved and highly codified form of storytelling; the more effective, the more it is linked to the telling of real stories that highlight from time to time crucial elements of the discipline being learned.

Studies in Physics Education Research (PER) underly that storytelling fosters pupils' creativity and positive attitude towards science [35]. It also offers a methodology guide to teach science in the laboratory. For example, teachers can use it to introduce a scientific problem in the form of a story for students to solve, possibly incorporating real-life scientific issues that researchers face in their everyday lives [26, 32]. Storytelling has always been a medium to transfer traditional knowledge, beliefs, values, and practices over time, and its core relies on sound education pedagogy [36, 37, 38]. Formal programs in school included aspects of storytelling that were used to raise students' interest and to encourage students to participate in learning [39] actively, but new forms of digital storytelling seem to replace them [34, 40, 41]. Nevertheless, role-play, dramatization, and storytelling will continue to hold promise for creating exciting, engaging, meaningful, and rewarding classroom experiences. Even in a technological environment, storytelling will remain a versatile option for teachers to introduce science in the classroom.

The specific focus of this work is on the use of storytelling to bring contemporary physics topics in high school and, in particular, black hole and gravitational waves physics. Specifically, this work aims to explore the effect of storytelling on students' levels of classroom participation, motivation, and interest in the proposed topics. We also meant to measure their engagement and, most interestingly, their views about the effectiveness of storytelling as a teaching/learning strategy in the science classroom. The research can give instructors a methodological tool to encourage them to bring these topics to school, using storytelling to optimum advantage in science, introducing students to current trends in research, trying to bypass content-related difficulties (both physical and mathematical) but still making them explore our Universe with inquiry and mind-on activities, improving their motivation, curiosity, and interest in physics.

More specifically, our research questions were the following:

- RQ1: How do students react to an activity that engages them with storytelling dealing with contemporary physics?
- RQ2: How does our activity affect students' engagement levels, motivation, and interest in science communication and contemporary physics?
- RQ3: What are students' feedback on using storytelling and artistic tools as a teaching/learning strategy in the science classroom?
- RQ4: Are there any gender, class, or school differences in students' feedback on the investigated domains?

In this paper, we address our research goals by reporting from an educational program developed by the PER group at the University of Cagliari, which makes use of storytelling and theatrical techniques (a monologue) to bring general relativity and gravitational-related topics such as gravitational waves and black hole physics at high-school. We briefly illustrate the physical background and the design of the educational program. The activity involved 200 students (17 - 19 years old) from five schools in Sardinia. We measured the efficacy of our activity according to our research goals using a post-questionnaire. We report and discuss our results, pointing out the potentiality of our approach in orientating students towards a STEAM (STEM and arts) career.

2. Physics framework and the monologue

In the context of contemporary physics, General Relativity (GR) gives the possibility of carrying out some educational experimentation considering the use of stories and storytelling. Indeed, in a broader sense, GR topics are related to the world views held by students, such as our Universe, stars, and planets, thus providing conceptual, theoretical, and experimental means for bridging the gap between the teaching of science and the teaching of humanistic subjects. For example, this is true for cosmology concepts like the Big Bang, which connects physics with philosophy [42, 43]. Students' first approach to these contents comes from movies, documentaries, media, and TV shows, shaping their conceptions about astrophysical phenomena. Experts should guide them toward understanding our Universe, stimulating the debate, and offering a modern vision of phenomena around us [7, 12]. It also offers the possibility to debate about what is science and what is not, what can be measurable and what is not, thus re-enforcing their critical thinking [43].

Let us make an explicit example for the sake of completeness. The concepts of "Big Bang" and "black hole" are metaphors. Physicists use them to explain and imagine phenomena which are invisible to their senses, whose physical meaning is obscure. They are a linguistic expedient that represents a way to move from a provisional ad hoc model (for example, an explosion or a dark, deep hole, respectively) to a permanent theory (GR) [6, 44, 25]. From the educational point of view, they have the potential to grasp and hold students' attention while quickly encouraging them to participate, share, and collaborate to learn. Telling the Universe using such metaphors is not only an artistic and linguistic tool, but it also has an educational purpose, giving the possibility to teachers to explore contemporary physics topics in class, living the contemporaneity of research and its methodologies [45].

More in detail, the word "black hole" describes the final state of matter when a massive star (with more than 1.4 Solar masses) explodes. The term was coined by the physicist Robert Dicke circa 1960 when he drew the analogy of this peculiar object to the Black Hole of Calcutta, a small prison notorious for its cramped conditions where on one occasion almost all prisoners were suffocated [46]. Indeed, there are not any "holes" in our Universe. However, this metaphor pictorially represents 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 or by detecting the gravitational waves produced by the merger of two black holes. Indeed, in 2016, after 100 years of Einstein paper [47], the LIGO and Virgo collaborations first announced the discovery of gravitational waves, ripples of spacetime traveling all around the Universe at the speed of light produced by violent astrophysical events [48]. An interesting feature of such waves is that their effect is to modify space and time, measuring changes in length much smaller than the diameter of an atomic nucleus (for a merging of black holes with masses of the order of ten Solar masses, the change in length is of the order of 10^{-21} cm, see [48]). Moreover, in 2019, researchers from the Event Horizon Telescope collaboration published a "picture" of the first image of the shadow of the supermassive black hole at the center of the M87 galaxy [49], replicated in 2022 with the first image of the black hole at the center of our galaxy, the Milky Way [50].

The search for understanding our Universe is ongoing, and researchers are looking for new technologies and devices to study its features, mainly in their initial stages. Indeed, no light signal could be detected from satellites or telescopes on the ground when stars were not formed. So, standard astronomical observation cannot give us any information about the first million years of our Universe. At that time, no matter or light signal existed, and only primordial quantum fluctuations populated the Universe, probably growing, collapsing, and forming primordial black holes. Thus, in principle, some primordial gravitational signals could be detectable [51, 52]. The Einstein Telescope (ET) experiment [53], a ground-based third-generation gravitational wave interferometer, will reach this goal, exploring the Universe with gravitational waves up to cosmological distances. ET has a reference configuration based on a triangular shape consisting of three nested detectors with 10 km arms, where each detector has a "xylophone " configuration made of an interferometer tuned toward high frequencies and an interferometer tuned toward low frequencies and working at cryogenic temperature [52]. Its scientific output is related to compact binary coalescences, multi-messenger astronomy, and stochastic backgrounds. The detector will be capable of observing the entire Universe using gravitational waves aiming to increase a factor ten the sensitivity of previous generation detectors [54]. It could be operating in the mid-2030s in Europe, and one of the site candidates is in Sardinia (Italy). This site has peculiar features (very low anthropomorphic, electromagnetic, and geophysical noises in the range of frequencies ET will operate), making it one of the best candidates to host the infrastructure [55].

2.1. The monologue

The possibility for Sardinia to host the experiment motivates us to design a suitable activity to bring gravitational waves physics contents and ET physics to high school. From a methodological point of view, we use storytelling and theatrical techniques such as a monologue. The latter is called "Viaggio in una storia lunga 14 miliardi di anni" ("A 14 billions years old journey"). The storytime is set in the middle of 2030 when ET should be operating. The story's protagonist is a physicist currently part of the ET collaboration, working on gravitational wave physics. He is in the control room of ET in Sardinia, checking for all the parameters coming from the detector in the underground caves, from optics to lasers. While thinking about his past, career, life as a researcher, studies, and work in Sardinia, he also checks for possible gravitational wave signals appearing on a monitor before him. At that moment, he started traveling all around the Universe, from Sardinia to the Universe's origin. In this 14 billion years journey back in time, he describes the relativistic effects of traveling back in time at the speed of light, the structures in our Universe, and their formation, unless he encounters a mysterious phenomenon he realizes to be a black hole merging. It allows him to tell the physics of tidal disruption and the consequent formation and propagation of gravitational waves. Finally, he travels back home, surfing such gravitational waves. Once he returned to the control room, he realized he had discovered a primordial gravitational wave signal. The monologue (in Italian) can be found at the following link: `https://www.youtube.com/watch?v=SMaNFRKdy4c`.

3. Methods

The activity was held in Sardinia, Italy, in 2023, along with the informal learning educational program at the Physics Department of the University of Cagliari and the Cagliari Division of the National Institute of Nuclear Physics (INFN). It involved 200 students (17-19 years old) from five high schools in the Region (four scientific lyceums, one humanities). In Italy, high school lasts five years, and students participating in the activity attend third-to-fifth-year classes.

The organization of the activity was as follows: the first 20 minutes was dedicated to the monologue, followed by a 20-minute session where the researcher explained gravitational-related contents and ET physics (gravity according to general relativity, black holes, gravitation waves formation and propagation, detection of gravitational waves with ET, cosmology). Finally, the final 20 minutes were for debate, discussions about physics and the contents of the monologue. At this stage, no feedback on the structure of the activity or any other issue concerning student's learning, motivation, or engagement was collected or qualitatively investigated.

During the monologue, some poems both in Italian and Sardinian language ‡ were used to tell some facts concerning physics. This served as an artistic tool and reinforced the character's identity, also related to the ET location in the story.

Trying to answer our research questions, we built a specific research questionnaire. In this way, we could quantitatively measure their engagement and their perception of the efficacy of storytelling as a teaching/learning strategy in the science classroom. We identified five dimensions corresponding to eight aspects to investigate: general information (demography - 5 items; preliminary knowledge on the proposed topic - 6 items); interest in STEM and engagement (interest and passion in STEM - 2 items; engagement - 4 items); communication and artistic tools (the monologue - 8 items; the poems - 5 items); motivation (3 items); final remarks (8).

‡ The Sardinian language, with its several variants all along the Island, descends from Latin with some words remaining from the ancient Nuragic language, and it is currently spoken in Sardinia. It is generally no longer taught in school, apart from some specific projects pertaining mostly to primary schools, but people learn it mostly at home.

Students could answer using a 6-point Likert scale from 1 (completely disagree) to 6 (completely agree). The questionnaire was written in Italian and imported into Microsoft Forms. We distributed it as a link via email to teachers to send it to their students at the end of the activity. Students' participation was voluntary, with no positive or negative inducements. We collected answers from a few days after the activity's end to forty days later.

We conducted a descriptive analysis of the data. After that, to determine whether there were statistically significant differences between means of domains based on schools, classes, and gender, we conducted a multivariate variance analysis (MANOVA). We also tested correlations among the domains with the "r" of Pearson coefficient. We investigated the reliability of the questionnaire in terms of internal consistency by Cronbach's alpha; the mean value among the domains was 0.89 (higher than the standard 0.8 threshold).

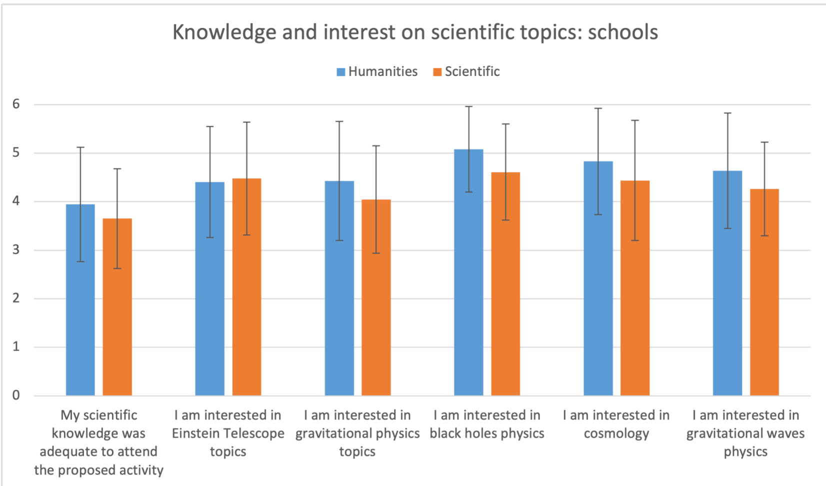

Figure 1. The panel shows means and standard deviation (error bars) about students' interest in the proposed topics according to the type of school. Students rated using a 6-point Likert scale, from 1 (completely disagree) to 6 (completely agree).

4. Results

We collected 76 answers, 23 from humanities and 52 from scientific high school students (1 missing answer). Regarding gender, 48 were females, 27 males, and 1 "other". Concerning classes, 28 attended the third, 39 the fourth, and nine the fifth. We first show general results and then display school, class, and gender results. After a general overview, we will focus on school, class, and gender results by 75 students (removing the case with missing data, i.e., "other").

Firstly, we asked students if, before attending the activity, they knew the ET project: 45 answered "no", 31 "yes". Concerning the first macro domain, "general information", we asked if students' preliminary knowledge was adequate to attend the activity: for 16 (21%) of them, their preparation was not adequate; 6 (8%) did not know;

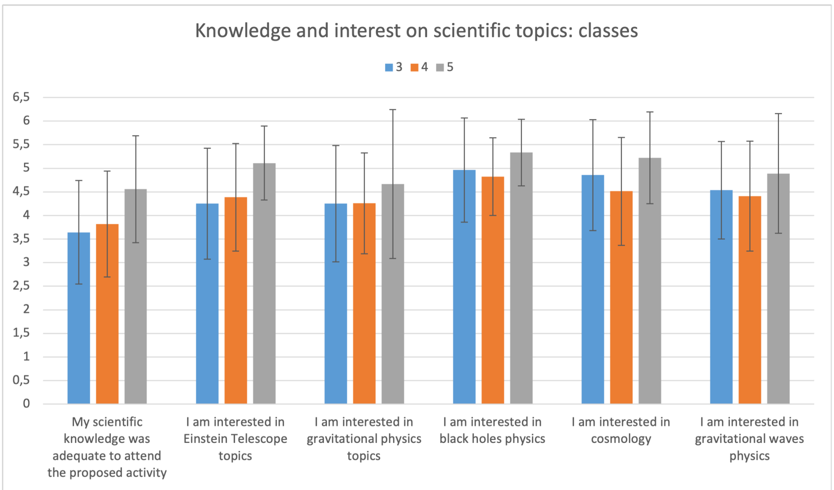

Figure 2. The panel shows means and standard deviation (error bars) about students' interest in the proposed topics according to the class. Students rated using a 6-point Likert scale, from 1 (completely disagree) to 6 (completely agree).

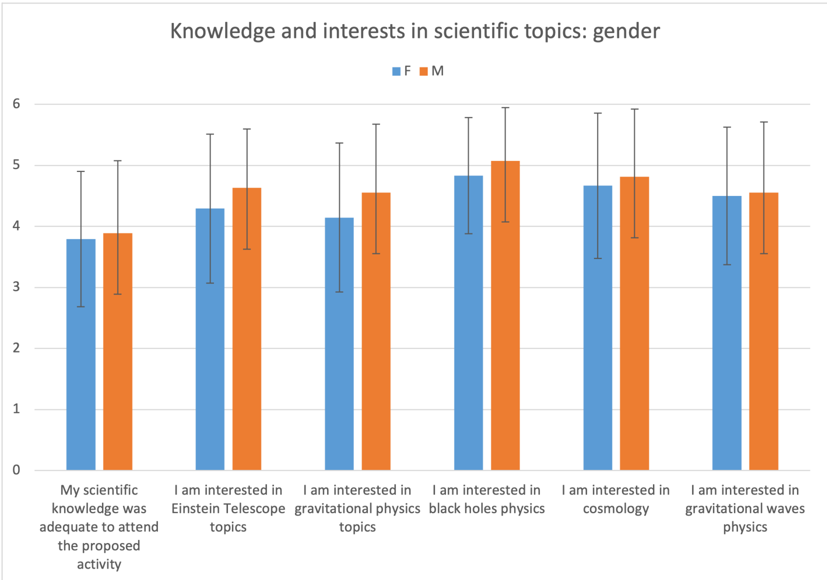

Figure 3. The panel shows means and standard deviation (error bars) about students' interest in the proposed topics according to their gender. Students rated using a 6-point Likert scale, from 1 (completely disagree) to 6 (completely agree).

29 (38%) answered that their preparation was adequate; for 24 (32%) students their preparation was adequate and one student reported to have high adequate preparation.

We also asked about their interest in the topics we proposed. Results are in Table 1. Concerning the type of school, results are shown in Fig. 1. Accordingly, results concerning the class and the gender are in Figs 2 and 3.

Concerning STEM Engagement and interest (from now-on "STEM Engagement"), we asked if students are interested in science communication, i.e. in outreach and dissemination activities: one student (1.3%) was not interested at all, 12 (15.8%)

Interest in monologue's topics							
	Completely Disagree	Disagree	Indifferent	Slightly Agree	Agree	Completely agree	Total Mean (Standard Deviation)
Einstein Telescope	1 (1.3%)	3 (3.9%)	9 (11.8%)	28 (36.8%)	20 (26.3%)	15 (19.7%)	4.4 (1.1)
Gravitational physics	2 (2.6%)	2 (2.6%)	15 (19.7%)	21 (27.6%)	24 (31.6%)	12 (15.8%)	4.3 (1.2)
Black holes	0 (0%)	0 (0%)	8 (10.5%)	11 (14.5%)	35 (46.0%)	22 (28.9%)	4.9 (0.9)
Cosmology	0 (0%)	1 (1.3%)	15 (19.7%)	12 (15.8%)	24 (31.6%)	24 (31.6%)	4.7 (1.1)
Gravitational waves	1 (1.3%)	3 (3.9%)	7 (9.2%)	26 (34.2%)	23 (30.3%)	16 (21.1%)	4.5 (1.1)

Table 1. The table shows the number of answers (and corresponding percentage) for each point of the Likert scale, and the total mean (and standard deviation) on items concerning students' interest in topics presented during the activity.

were indifferent to such activities, 27 (35.5%) were slightly interested, 23 (30.3%) were interested and 13 (17.1%) were very interested in them. Concerning schools, classes, and gender, means and standard deviation are in Table 2.

Science communication (outreach and dissemination)							
	Humanities	Scientific	Class 3	Class 4	Class 5	Females	Males
I like science communication	4.4 (1.0%)	4.5 (1.0%)	4.8 (1.0)	4.2 (0.9)	4.9 (1.1)	4.3 (0.9)	4.6 (1.1)

Table 2. The table shows means (and standard deviation) on items concerning students' interest in science communication.

Students also gave their feedback about the role of science communication and outreach in society. In particular, we asked them if we need more science communication and outreach activities at school: 65 (85.5%) students answered "yes", 1 (1.3%) said "no" and 10 (13.2%) "I do not know". We also asked them if we need more science communication and outreach activities locally, all around the Region: 53 (69.7%) students rated "yes", 3 (3.9%) answered "no" and 10 (26.3%) "I do not know". Finally, we collected their feedback about the need for more science communication and outreach activities in our society: 65 (85.5%) answered "yes", 2 (2.6%) "no", and 9 (11.8%) "I do not know".

We also investigated students' feedback about the role of science communication (outreach and dissemination) as a tool to learn science (a) and to orientate people in choosing (b) and pursuing (c) an academic career. Finally, we also asked them if science communication drives their interest in science. We show results in Table 3.

In Figs 4 and 5, we show results divided per school, classes, and gender, respectively.

Concerning the macro-domain related to the monologue, we investigated eight different items to study the efficacy of the artistic tool on learning, motivation, engagement, and the presence of research infrastructure in Sardinia. We report the items and corresponding results in Table 4. School and class results are in Figs. 6.

Science communication							
	Completely Disagree	Disagree	Indifferent	Slightly Agree	Agree	Completely agree	Total Mean (Standard Deviation)
Science communication is usefull to learn science	0 (0%)	1 (1.3%)	3 (3.9%)	20 (26.3%)	29 (38.2%)	23 (30.3%)	4.9 (0.9)
Science communication orientates people in choosing a university course	0 (0%)	2 (2.6%)	11 (14.5%)	26 (34.2%)	26 (34.2%)	11 (14.5%)	4.4 (1.0)
Science communication motivates me in starting an academic career	6 (7.9%)	7 (9.2%)	17 (22.4%)	22 (28.9%)	12 (15.8%)	12 (15.8%)	3.8 (1.4)
Science communication drives my interest in science	1 (1.3%)	1 (1.3%)	11 (14.5%)	24 (31.6%)	26 (34.2%)	13 (17.1%)	4.5 (1.1)

Table 3. The table shows the number of answers (and corresponding percentage) for each point of the Likert scale, and total mean (and standard deviation) concerning the role of science communication in engaging students towards science.

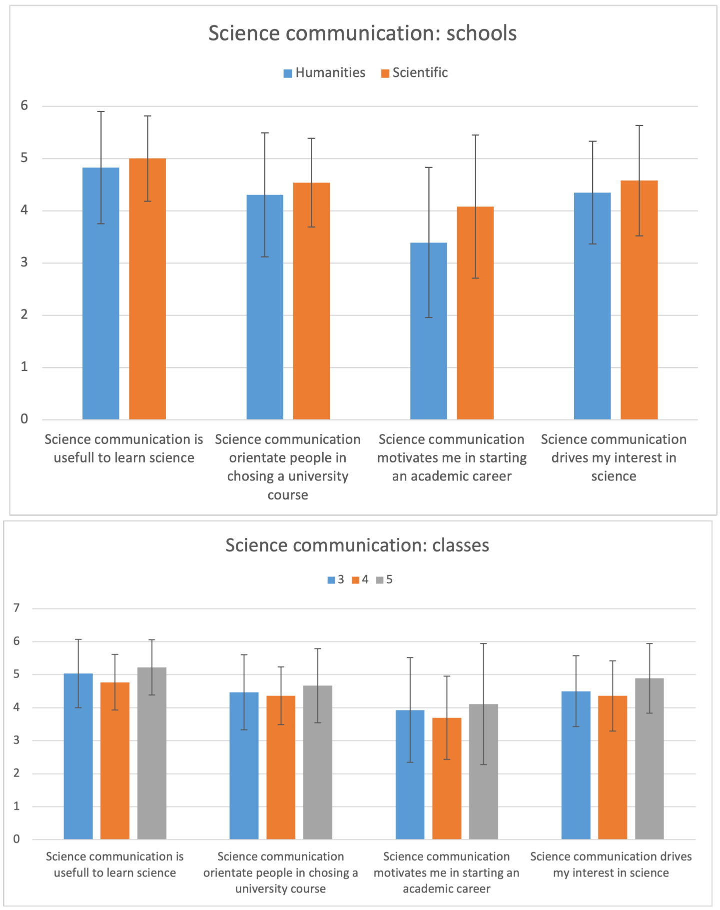

Figure 4. The panel shows means and standard deviation (error bars) about the use of science communication as a tool to engage students in STEM according to the type of school (above) and the classes (below).

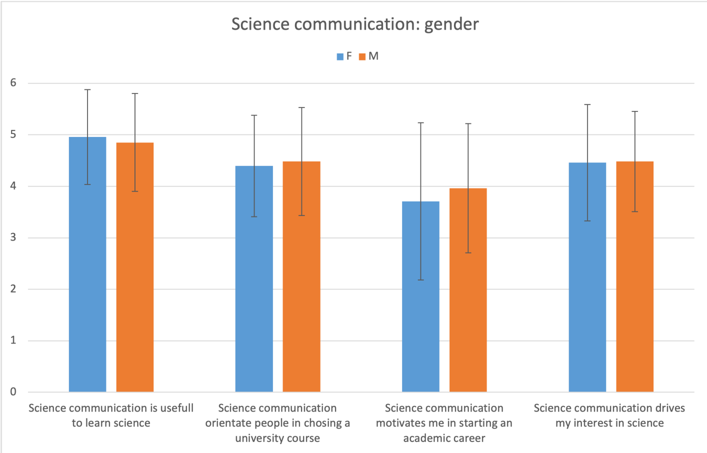

Figure 5. The panel shows means and standard deviation (error bars) about students' interest in science communication according to the gender.

The Monologue							
	Completely Disagree	Disagree	Indifferent	Slightly Agree	Agree	Completely agree	Total Mean (Standard Deviation)
I discovered new physics concepts thanks to the monologue	1 (1.3%)	8 (10.5%)	11 (14.5%)	32 (42.1%)	14 (18.0%)	10 (13.2%)	4.1 (1.2)
The monologue fostered my interest in physics	1 (1.3%)	12 (15.8%)	12 (15.8%)	27 (35.5%)	16 (21.0%)	8 (10.5%)	3.9 (1.2)
The monologue stimulated my creativity	1 (1.0%)	11 (14.5%)	18 (23.7%)	18 (23.7%)	20 (26.7%)	8 (10.5%)	3.9 (1.3)
The monologue is a usefull tool to communicate physics	0 (0%)	5 (6.6%)	7 (9.2%)	30 (39.5%)	21 (27.6%)	13 (17.1%)	4.4 (1.1)
The monologue is a usefull tool to passionate people in physics	0 (0%)	2 (2.6%)	8 (10.5%)	31 (40.8%)	16 (25.0%)	19 (25.3%)	4.5 (1.0)
The monologue brought me into researchers' lives, making me live a research-like experience	4 (5.3%)	10 (13.2%)	11 (14.5%)	21 (27.6%)	19 (25.0%)	11 (14.5%)	4.0 (1.4)
The monologue made me know about research infrastructures in Sardinia	2 (2.6%)	2 (2.6%)	7 (9.2%)	29 (38.2%)	25 (32.9%)	11 (14.5%)	4.4 (1.1)
The monologue helped me in evaluating the importance of local research (in Sardinia)	2 (2.6%)	2 (2.6%)	7 (9.2%)	20 (26.3%)	28 (36.8%)	17 (22.3%)	4.6 (1.2)

Table 4. The table shows the number of answers (and corresponding percentage) for each point of the Likert scale, and total mean (and standard deviation) concerning students' feedback about the efficacy of the monologue on the selected domains.

Gender results are in Fig. 7.

Concerning the use of poems as an educational tool, we report the items and corresponding results in Table 5. School, classes, and gender results are in Figs. 8

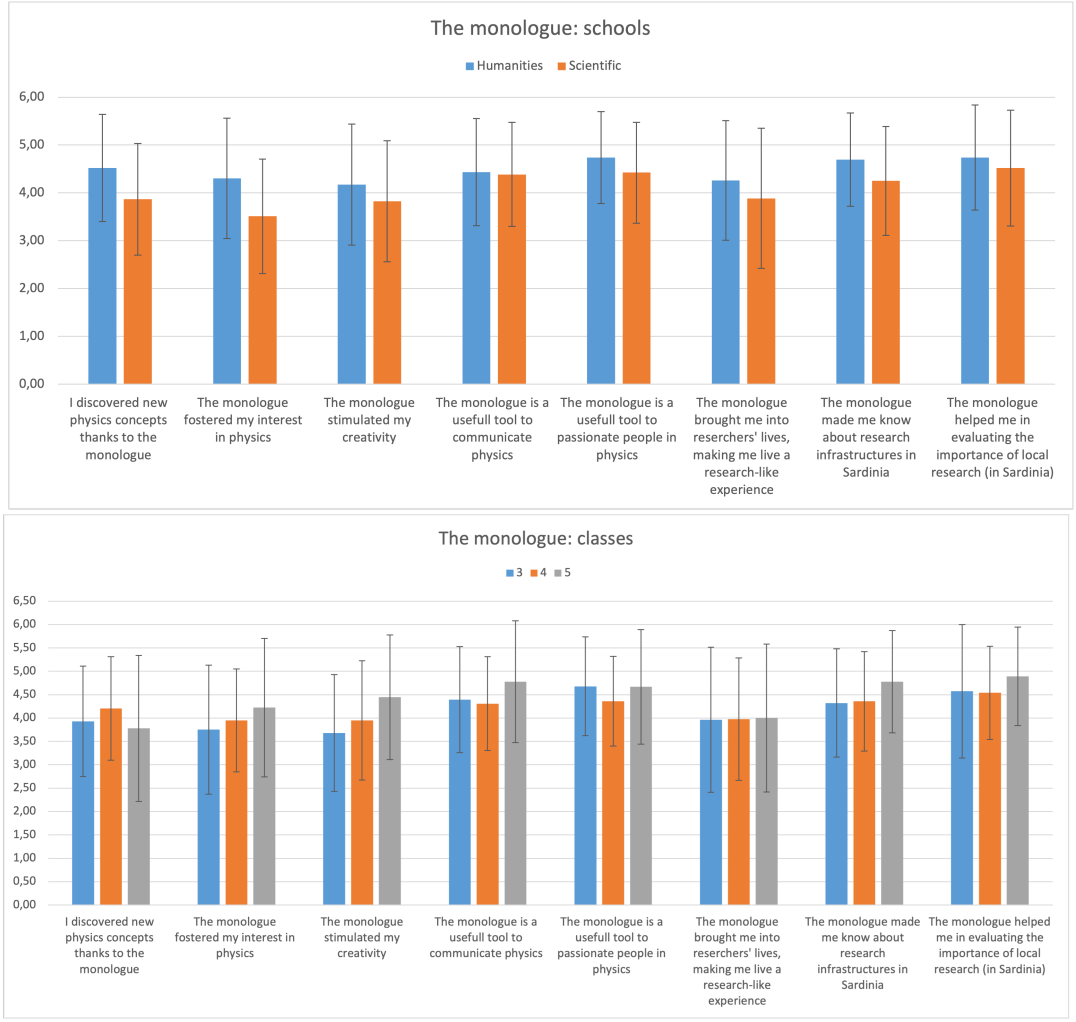

Figure 6. The panel shows means and standard deviation (error bars) about the use of science communication as a tool to engage students in STEM according to the type of school (above) and the classes (below).

and 9, respectively.

Concerning motivation, we report items and corresponding results according to the Likert scale in Table 6. School, classes, and gender results are in Figs. 10 and 11, respectively.

Finally, when asked if they would participate again in similar activities, 66 students (86.8%) answered "yes", 3 (3.9%) "no", and 7 (9.2%) "I do not know". The overall feedback on the activity was as follows: 1 (1.3%) rated as inadequate, 4 (5.3%) were indifferent, 15 (19.7%) slightly good, 30 (39.5%) rated as good, and 26 (34.2%) as very good.

4.1. Correlations and MANOVA

Concerning correlations, we report results in Table 7. All of them are significant for $p < 0.1$ (p stands for p-value).

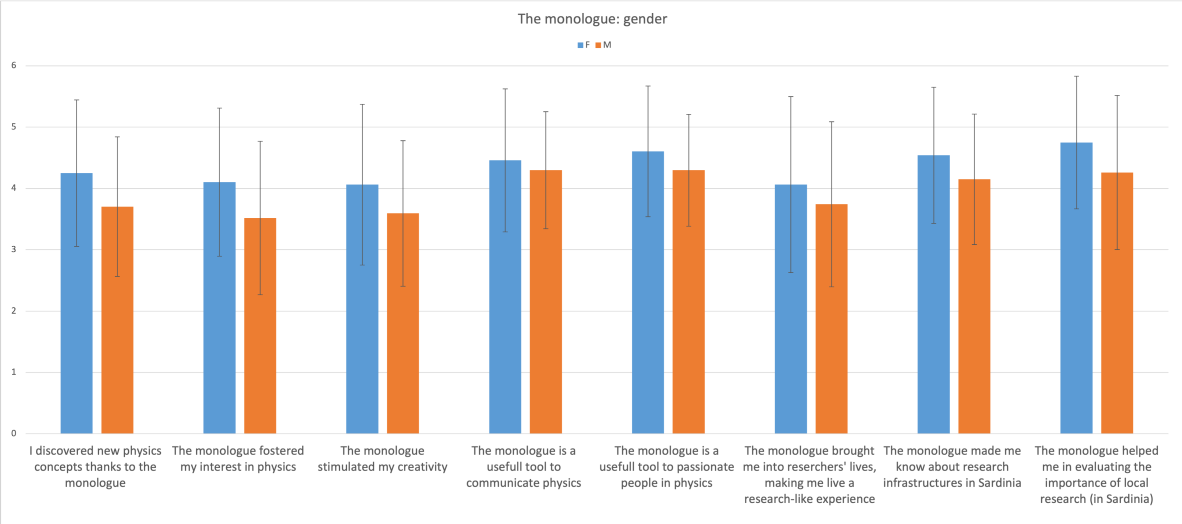

Figure 7. The panel shows means and standard deviation (error bars) about students' interest in science communication according to the gender. Students rated using a 6-point Likert scale, from 1 (completely disagree) to 6 (completely agree).

Poems							
	Completely Disagree	Disagree	Indifferent	Slightly Agree	Agree	Completely agree	Total Mean (Standard Deviation)
I liked the use of poetry within the monologue to talk about physics	4 (5.2%)	10 (13.1%)	7 (9.2%)	26 (34.2%)	18 (23.7%)	11 (14.5%)	4.0 (1.4)
Poems motivated me in carefully following the performance, taking care of the scientific contents of the monologue	3 (3.9%)	6 (7.9%)	16 (21.1%)	26 (34.2%)	19 (25.0%)	6 (7.9%)	3.9 (1.2)
Poems and the use of poetry captured my attention, fascinating me	4 (5.2%)	3 (3.9%)	13 (17.1%)	24 (31.6%)	19 (25.0%)	13 (17.1%)	4.2 (1.3)
Poems are a useful instrument to communicate science (physics)	4 (5.2%)	11 (14.5%)	22 (28.9%)	16 (21.0%)	16 (21.0%)	7 (9.2%)	3.7 (1.4)
Poems and the use of poetry stimulated my creativity	6 (7.9%)	6 (7.9%)	19 (25.0%)	20 (26.3%)	20 (26.3%)	5 (6.6%)	3.8 (1.3)

Table 5. The table shows the number of answers (and corresponding percentage) for each point of the Likert scale, and total mean (and standard deviation) concerning students' feedback about the use of poems as an educational tool.

The results of the MANOVA concerning differences between means of dimensions related to "Preliminary knowledges", "STEM Engagement", "The Monologue", "Poems", and "Motivation" according to gender, school and classes showed a significant multivariate difference only for the school (Wilkis lambda .704, F = 5.05, $p < 0.1$).

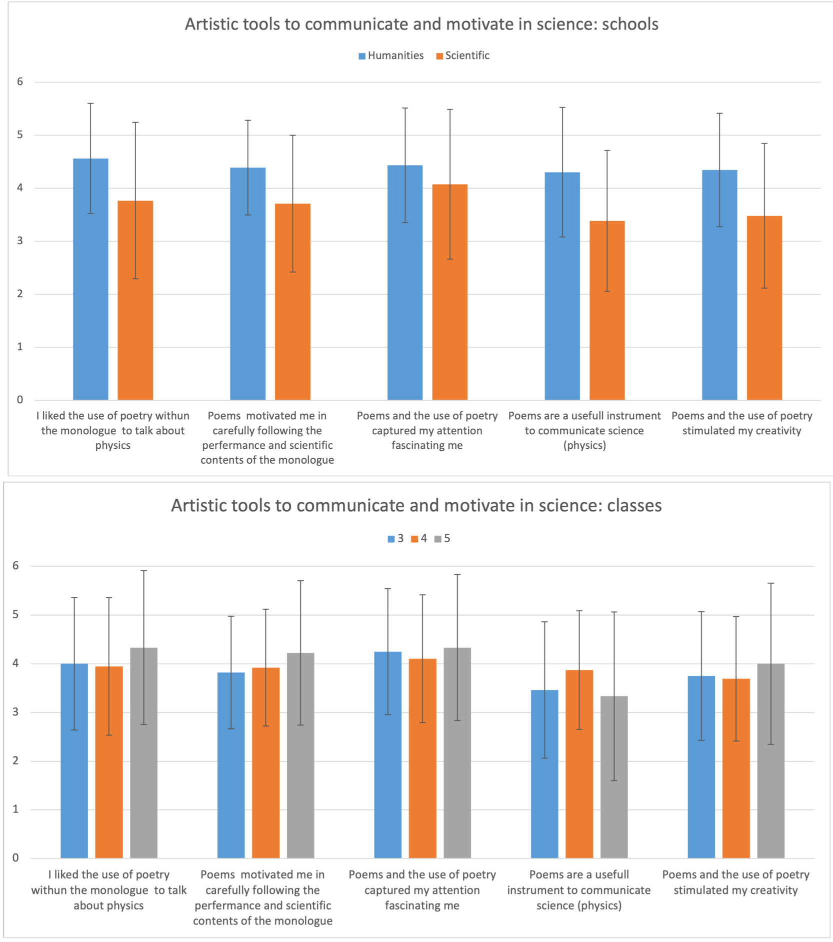

Figure 8. The panel shows means and standard deviation (error bars) about the use of poems within the monologue as an educational tool according to the type of school (above) and the classes (below).

Motivation in learning physics							
	Completely Disagree	Disagree	Indifferent	Slightly Agree	Agree	Completely Agree	Total Mean (Standard Deviation)
The activity motivated me in studying physics	9 (11.8%)	9 (11.8%)	20 (26.3%)	22 (28.9%)	10 (13.2%)	6 (7.9%)	3.4 (1.4)
The activity motivated me in studying physics	3 (3.9%)	10 (13.2%)	20 (26.3%)	14 (18.4%)	20 (26.3%)	9 (11.8%)	3.9 (1.4)
The activity motivated me in studying gravitational physics related-contents in the future	4 (5.2%)	5 (7.9%)	18 (23.7%)	19 (25.0%)	16 (21.1%)	13 (17.1%)	4.0 (1.4)

Table 6. The table shows the number of answers (and corresponding percentage) for each point of the Likert scale, and total mean (and standard deviation) concerning students' feedback about the use of poems as an educational tool.

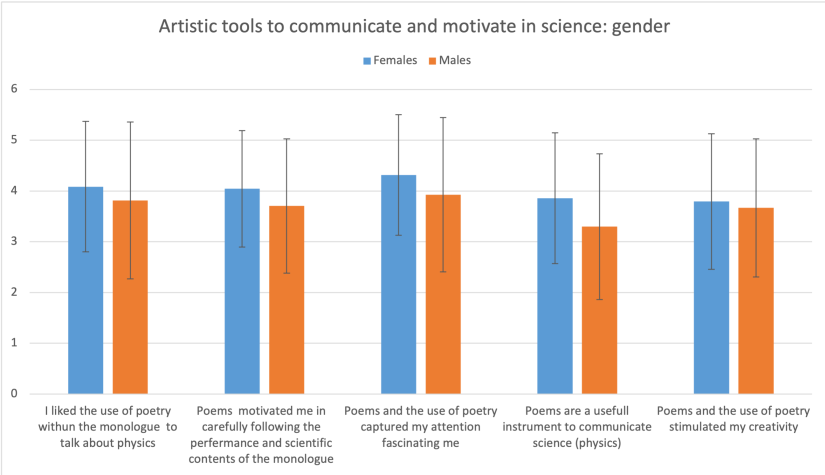

Figure 9. The panel shows means and standard deviation (error bars) about the use of poems within the monologue as an educational tool according to the gender.

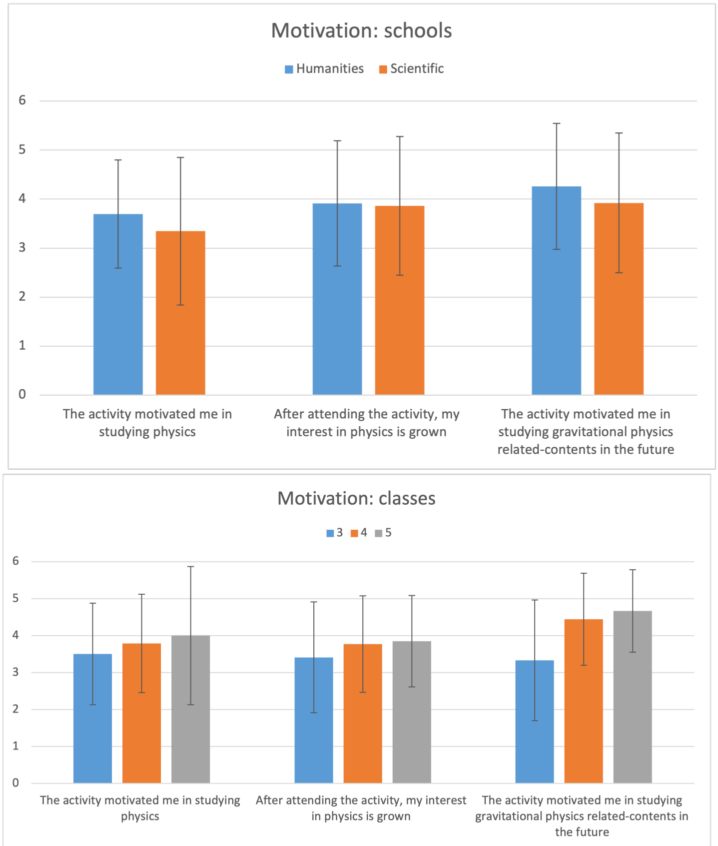

Figure 10. The panel shows means and standard deviation (error bars) about students' motivation in learning physics and the proposed subjects after attending the activity according to the type of school (above) and the classes (below).

In particular, the differences are associated to "STEM Engagement", "The Monologue", "Poems". Concerning "STEM Engagement", the means are higher for scientific schools, whereas the means are higher for humanities in the "Monologue", and "Poems"domains,

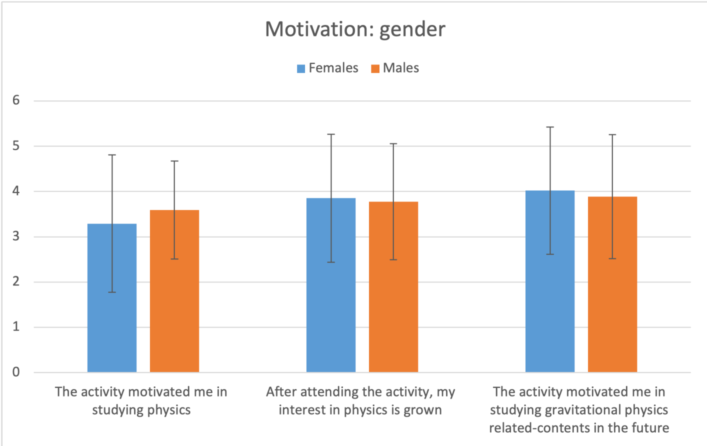

Figure 11. The panel shows means and standard deviation (error bars) about students' motivation in learning physics and the proposed subjects after attending the activity according to the gender.

see Tables 8, 9, 10.

Correlations						
		Preliminary Knowledges	STEM engagement	Monologue	Poems	Motivation
Preliminary Knowledges	Pearson correlation	1				
STEM engagement	Pearson correlation	.656	1			
Monologue	Pearson correlation	.523	.483	1		
Poems	Pearson correlation	.356	.320	.734	1	
Motivation	Pearson correlation	.604	.600	.637	.564	1

Table 7. The table shows correlations between macro-domains investigated. All of them are significative for $p < 0.1$.

STEM Engagement				
	N	Mean	Std. Dev.	Std. Err.
Humanities	23	4.26	0.92	0.19
Scientific	52	4.54	0.79	0.11
Total	75	4.46	0.84	0.09

Table 8. Means, standard deviation and standard error for the "STEM Engagement" domain.

Monologue				
	N	Mean	Std. Dev.	Std. Err.
Humanities	23	4.48	0.96	0.20
Scientific	52	4.11	0.97	0.13
Total	75	4.23	0.97	0.11

Table 9. Means, standard deviation and standard error for the "Monologue" domain.

Poems				
	N	Mean	Std. Dev.	Std. Err.
Humanities	23	4.41	0.99	0.21
Scientific	52	3.68	1.21	0.17
Total	75	3.91	1.19	0.14

Table 10. Means, standard deviation and standard error for the "Poems" domain.

5. Discussion

We studied the use of storytelling and artistic tools to bring contemporary physics topics and, in particular, black hole and gravitational waves physics at high school. This work aimed to explore the effect of storytelling on students' levels of classroom participation, motivation, and interest in the proposed topics. We also meant to measure their engagement and, most interestingly, their views about the effectiveness of storytelling as a teaching/learning strategy in the science classroom. To do so, we designed a specific activity we proposed to 5 schools in Sardinia, Italy (200 students involved). The activity started with a monologue about the physics of ET and its possible implementation in Sardinia. The monologue used storytelling and poems, the latter being both in Italian and Sardinian language and related to the physical content of the story. After that, a 20-minute session to explain the physics of ET and gravitational waves occurred. In particular, we focused on gravity according to GR, black hole and gravitational wave formation, cosmology, and the early Universe as possibly studied by ET. The activity ended with a 20-minute session of debate, where students asked questions and raised their curiosity about the proposed topics. To measure the efficacy of our activity, we wrote a research questionnaire to investigate specific domains. Our results are quite encouraging in many aspects.

Even if the majority of students did not know ET project, infrastructure, or physics, regardless of the type of school or class, they rated their average scientific preparation as adequate to attend the activity. Means are slightly higher for scientific and the fifth class concerning humanities and the third and fourth classes, respectively. This result is encouraging. Teachers and researchers can discuss such topics at school without specific preparation. If we look at classes, students attending the third and fourth classes have a lower mean than their colleagues in the fifth class. This result is likely related to the fact that these contents are far from the scholarly curriculum and that their preparation in mathematics and physics was at a starting level. Students did not know many concepts the monologue dealt with, such as the one of "field" (e.g., electromagnetic field) or "wave". Let us notice that no mathematics was used during the monologue.

In particular, students' higher interest was in black hole physics and cosmology. These findings are confirmed also in the case of the type of school, with means generally higher for humanities than the scientific. In the case of classes, the general trend is respected, and the means are higher for students attending the fifth class than the others. Concerning gender, males showed slightly higher means than their female colleagues in all the items investigated within this domain.

Students reported having a high interest in science communication, where we intended outreach and dissemination activity; see Table 1. Science communication as a tool to learn science was rated with high votes by most students, thus suggesting that activities like the one we designed can be considered a supplementary tool in teaching and learning. One-half of the sample rated with high votes the role of science communication in driving its interest in science and orientating them to university (see Table. 3). When asked if science communication activities motivated them to start an academic career, the mean appeared lower than the other items. A possible interpretation of this result is that even if this kind of activity can, in some sense, help in orientating students toward a particular university course, raising their interest in science, it is not evident that they will pursue such a career. Nevertheless, students affirmed that through this kind of activity, they had entered into contact with science, learning new concepts.

Using an artistic tool such as the monologue, which, in turn, means using storytelling to tell physics, inspired students to pursue the subject proposed. They also evaluated it as a valuable instrument for communicating science. Implementing these strategies in the classroom during formal curriculum can engage students in science. Moreover, most students affirmed they had learned new physics concepts thanks to the monologue, raising their interest in physics, see Table 4. Concerning creativity, we did not collect very high votes, but if we look at the type of schools, the humanities showed higher means than the scientific ones. We can also look at the class distribution to understand why the global mean is not so high (see Fig. 6). Students attending the third and fourth classes exhibited lower means than their colleagues attending the fifth class (and students attending the third and fourth classes represent the majority of the sample). We can relate this result to their lower level of preparation in physics, thus suggesting that the contents of the monologue could be more appropriate for students attending the last two years of high school. However, if we look at the capacity of storytelling to passionate people, no differences between classes appeared in the data. Concerning gender, females reported slightly higher means than males (see Fig. 7).

A similar situation appears in the use of poems within the monologue. Interestingly, when one looks at the school distribution of data, humanities reported higher means for every item we investigated concerning this domain. Statistical analysis reveals that the difference is significant, thus suggesting that the use of artistic tools to communicate physics and an educational tool is welcome in humanities which, in turn, suffer from the lack of science in their curriculum. It is our main result, which is also corroborated by the findings in the other domains we investigated. During the debate phase, some of the students attending humanities reported that they are not suitable for pursuing a scientific career. If interdisciplinary approaches based on storytelling can bring science and, in particular, physics to school, teachers could think about implementing specific programs based on this methodology during their in-class activities. Students reported that using poems captured their attention, motivated them to attend the activity, and stimulated their creativity, in the case of humanities, too. Poems can offer students the possibility to put humanistic and scientific knowledge together, stimulating their critical thinking skills, as also suggested by [42] in the case of cosmology. The MANOVA confirms this result (see Tables 8, 9, 10), where significative differences according to the school appeared between the following domains: "STEM Engagement", the "Monologue", and "Poems". Students from the humanities rated the items appertaining to these domains with higher votes, thus suggesting the positive influence of our methodology in engaging, interesting, and passionate them towards gravitational physics.

Finally, even if students do not appear to be highly motivated to pursue a career in physics (as noted before in the case of science communication items), they want to learn more about gravitational wave physics. At first sight, this result appears counterintuitive. However, let us notice that for high school students, studying physics is different from studying astronomy or astrophysics; thus, they can be interested in learning more gravitational physics but not in studying physics as a whole subject. This fact emerged during the debate phase of the activity, where students made questions to satisfy their need for knowledge about physics. Students asked questions about black holes, white holes, dark matter, dark energy, the expansion of the Universe, and quantum gravity. The expert stimulated the discussion, linking the answers to ET physics, whose fields of investigation will be promising to address many of the students' questions [51, 52]. The role of debate after science theatre has been emphasized in [11, 12] as essential to stimulate critical thinking and engage students in learning science, with particular attention to acquiring scientific literacy. Our results go in the same direction, which is to be taken into account by teachers during the design of a lesson.

If we look at correlations between the domains we investigated, we see that "Motivation" correlates with the "Monologue", and "Poem" domains. The correlation also appears with items related to "STEM Engagement", suggesting that the efficacy of an activity like the one we proposed relies on students' sensibility towards science communication and its role in our society to learn physics. Nevertheless, since motivation also correlates with the methodology we used to bring physics into the classroom, a positive effect of storytelling and interdisciplinary learning in this domain appeared. This result corroborates findings in the literature on the positive effects of storytelling and interdisciplinary approaches to bring STEM in high school, fostering engagement and learning [27, 29, 30, 35, 34]. Correlations could offer some insights into the cognitive mechanism of generating enthusiasm and fostering motivation in students, individuating the independent variables, which in our case are related to students' passion for science communication (outreach and dissemination).

Finally, the overall feedback about the activity is very positive, showing students' appreciation of our methodology and its possible implementation at school. In particular, we suggest this approach could help orient students toward a STEM or STEAM (Science, Technology, Engineering, Arts, and Mathematics) career, as discussed in [23, 24]. Our results reveal that the activity raised students' motivation to learn gravitational-related topics. They also found monologues and poetry to be valuable tools for communicating physics. Thus, their interest can also be driven towards studying arts and science communication (see also [56] and refs therein). In collaboration with researchers, teachers can design specific programs to integrate formal scholar curricula to engage students in these fields.

6. Conclusion

In this work, we proposed storytelling and artistic tools (a theatrical monologue) to bring gravitational waves physics to high school. The PER group of the University of Cagliari and INFN Cagliari designed a specific program devoted to 200 high school students (17 to 19 years old, third to fifth classes) in Sardinia.

Our work aimed to explore the effect of storytelling on students' levels of engagement (RQ1), classroom participation, motivation, and interest in the proposed topics (RQ2). We also meant to measure their views about the effectiveness of storytelling as a teaching/learning strategy in the science classroom (RQ3). We investigated these domains by self-report questionnaires administered to 76 students from scientific and humanities, and data were analyzed both qualitatively and quantitatively. This, in turn, allowed us to analyze our results concerning gender, school, and class (RQ4).

Concerning RQ1 and RQ2, the results are positive and encouraging. Students' level of engagement was high. They were motivated and interested in learning the proposed topics, and using artistic tools such as monologues and poetry raised their interest and motivation. Concerning RQ4, we found no significant differences between genders or classes for all the investigated items. However, our research findings reveal that students from humanities rated the use of arts and poetry as an educational tool with higher votes than their scientific colleagues. The difference was statistically significative, and the MANOVA confirmed these results even for other domains: "STEM Engagement", the "Monologue", and "Poems". This suggests the positive influence of our methodology in engaging, interesting, and passionate them towards gravitational physics.

The overall results of our research are encouraging. We hope they can also motivate high school teachers to explore this approach in their classes, at least to introduce new arguments or to engage more students in STEM. Our positive results concerning RQ3 also corroborate our idea. Indeed, students rated the possibility of using arts to tell and make physics at school as engaging and welcoming, even during in-class activities and not only during informal learning activities. If teachers do not feel adequate to explore by themselves this methodology, they can promote students' creation of stories to motivate them to learn physics (see [27, 40, 41]). In particular, statistical analysis showed that results are more favorable for humanities than scientific high school students. It is an encouraging result since humanities suffer from the lack of a proper scientific curriculum. If interdisciplinary approaches based on storytelling can bring science and, in particular, physics to school, teachers could think about implementing specific programs based on a methodology like the one we proposed.

Offering an interdisciplinary vision of science to high school students and teachers is becoming a common trend of informal learning (see [1, 2, 3] and refs therein). To show how science is evolving and to provide new instruments to learn science and physics in an enlarged context, mixing knowledge, techniques, and methods from different disciplines should be part of science and education curricula, developing an integrated model of learning and teaching [5]. This research can give instructors a methodological tool to encourage them to bring these topics to school, using storytelling to optimum advantage in science. It can be used to introduce students to current trends in research, trying to bypass content-related difficulties (both physical and mathematical) while still making them explore our Universe with inquiry and hands-on activities, improving their motivation, curiosity, and interest in physics.

The study has some limitations that future investigations should take into account. The size of the sample does not allow for the identification of a model able to discriminate the cognitive factors important to improving the efficacy of our methodology. Carrying out interviews, also with a small sample, could help in this direction. A measure of the level of learning pre- and post-activity (formative evaluation) could also give important feedback to quantitatively measure the efficacy of the methodology on learning.

Another issue concerns the questionnaire's structure. We posed the Likert scale so that "1" is the most negative and "6" is the most positive. While this facilitated data analysis, it could bias the results with respondents who simply filled out a column quickly. Rephrasing some of the questions to reverse the order of positive-to-negative may be helpful to avoid or at least identify this potential bias in the future. It might also be interesting to see if there is a significant difference in the responses when a female researcher or someone else (minorities, for example) delivers the monologue. Another possible investigation is to reproduce the study with students themselves primarily involved in using storytelling to tell physics, even in formal in-class activities. They should be involved in choosing the topic and writing and delivering the monologue. We left these studies for future investigations.

7. Acknowledgments

The authors acknowledge faculty members, teachers, and students who participated in our studies. The authors also acknowledge the anonymous referee for the careful revision of the paper and for the helpful comments which raised the quality of the work.

8. Ethical statement

Informed consent to participate in the study has been obtained from participants. Any identifiable individuals participating at the study have been also aware of intended publication. Informed consent to publish has be 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.

9. Funding declarations and conflicts of interests

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.

10. Data availability statement

Any data that support the findings of this study are included within the article.

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12. Biography

Matteo Tuveri is a theoretical physicist and a science communicator. He is a researcher at the University of Cagliari and the Cagliari Division of INFN in Physics Education Research and History of Contemporary Physics. He develops communication and teaching methodologies between art, technology, history, philosophy, and science to foster the learning of physics and train schoolteachers. His research also focuses on studying the cognitive mechanisms of learning, linking natural and mathematical languages to promote the conceptual understanding of physics. He collaborates with schools and institutions in regional and national contexts.

Arianna Steri is a chemical engineer. She is a Ph.D. student at the University of Cagliari and a researcher at the Cagliari INFN section. She studies the cryogenic distillation of stable isotopes for medical and high-energy physics applications. In teaching, she studies problem-solving and the effectiveness of interdisciplinary methodologies in engaging high school students in STEM.

Daniela Fadda graduated in psychology from the University of Cagliari (Unica) and received a Ph.D. in cognitive and personality psychology from the University La Sapienza in Rome and a Ph.D. in pedagogy at Unica. Her research experience included well-being and school adjustment in adolescence and the study of digital technologies for scientific education. She is a member of the Italian Association of Psychology and an Associate Editor for Frontiers in Psychology. She has published several research papers on psychological well-being, self-concept, motivation in mathematics, cognitive performances, and educational technology. Her scientific interests also include methodology and statistics for human sciences, particularly factorial analysis, structural equation modeling, and meta-analysis.