digital

Article

Fostering the Interdisciplinary Learning of Contemporary Physics Through Digital Technologies: The "Gravitas" Project

Matteo Tuveri [1,2,*], Arianna Steri [2,3], Daniela Fadda [4], Riccardo Stefanizzi [1,2], Viviana Fanti [1,2] and Walter Marcello Bonivento [2]

[1] Physics Department, University of Cagliari, Cittadella Universitaria di Monserrato, 09042 Monserrato, Italy; riccardo.stefanizzi@ca.infn.it (R.S.); viviana.fanti@ca.infn.it (V.F.)
[2] INFN Sezione di Cagliari, Cittadella Universitaria di Monserrato, 09042 Monserrato, Italy; arianna.steri@ca.infn.it (A.S.); walter.bonivento@ca.infn.it (W.M.B.)
[3] Department of Mechanical, Chemical and Material Engineer, University of Cagliari, via Marengo 2, 09123 Cagliari, Italy
[4] Department of Pedagogy, Psychology, and Philosophy, University of Cagliari, via Is Mirrionis, 09123 Cagliari, Italy; danielafadda@unica.it
* Correspondence: matteo.tuveri@ca.infn.it

Abstract: The interdisciplinary teaching of contemporary physics has become increasingly common in physics education, especially for high school students and teachers. This approach, which integrates content and methodologies from various disciplines, fosters scientific reasoning, enhances creativity, and increases student motivation and interest in physics. The use of digital technologies, such as social media platforms, supports these educational goals by facilitating the inclusive and cost-effective dissemination of scientific knowledge and the development of soft skills. This paper introduces the "Gravitas" project, an initiative that employs an interdisciplinary approach to present contemporary physics topics to high school students through social media. Coordinated by the Cagliari Division of the National Institute of Nuclear Physics (INFN) in Italy, the "Gravitas" project offers a non-traditional learning environment where students explore modern physics and philosophy and the history of science. Through the creation of educational materials, such as social media posts, students actively engage in their learning. In 2022, around 250 students from 16 high schools across Sardinia, Italy, participated in this project. This paper discusses the learning outcomes, highlighting the potential of integrating formal high school curricula with innovative educational and digital tools.

Keywords: interdisciplinary; physics education; informal learning; online learning; digital technologies

Citation: Tuveri, M.; Steri, A.; Fadda, D.; Stefanizzi, R.; Fanti, V.; Bonivento, W.M. Fostering the Interdisciplinary Learning of Contemporary Physics Through Digital Technologies: The "Gravitas" Project. *Digital* **2024**, *4*, 971–989. https://doi.org/10.3390/digital4040048

Academic Editor: Geoffrey Fox

Received: 6 September 2024
Revised: 12 November 2024
Accepted: 18 November 2024
Published: 19 November 2024

1. Introduction

Technological advances have created new instructional activity opportunities as a driving force capable of supporting student learning and motivation [1]. Some promising findings regarding the efficacy of online learning strategies in enhancing students' academic performance in physics are documented in the literature [2–4], even when compared to results from traditional learning approaches [5–7]. Scientific evidence suggests that the influence on learning outcomes heavily depends on the quality of teaching rather than on the technological applications themselves [8,9]. Since the time of social distancing imposed by the SARS-CoV-2 pandemic, the use of technologies has opened a new window to physics teaching in schools and academia. Advances in information technology have led to the development of innovative and interactive technological applications that aid in better understanding concepts, phenomena, and scientific theories by students, offering an active learning environment conducive to fostering essential skills such as critical thinking and problem-solving abilities [10]. However, several recent publications confirm that technological applications in schools have a limited or moderate impact on learning outcomes, albeit with considerable variability in the data.

Nevertheless, the consumption of physics-related media on social networks is also increasing thanks to all science communicators' work. Scientific evidence suggests that learning outcomes heavily depend on the teaching quality rather than the technological applications [8,9]. Concerning the online learning of physics, interactivity and constructivist-based active learning strategies are helpful tools to foster it, in both formal and informal contexts [10–19]. As a result of the explosion of social networks and the quick evolution of the media, today, the public can engage in dialogue and directly interact with experts, thus finally becoming active participants in the process of the dissemination of the research results and of the implications of these results for society [15]. The same happens in the education context, with a switch from a traditional way of teaching, where students act as passive subjects during a lesson or a lecture, to complete, active, and direct student participation in the learning process.

The online learning of physics on social platforms suits the purpose of the informal learning of science, ensuring inclusivity and a large and free diffusion of content. Students can attend the meetings in a synchronous (during the live session) or in an asynchronous way (when they prefer). The positive effects of asynchronous activities in the affective domain (interest, passion, motivation) are well studied in the literature (see [20] and references therein for details). Students learn at their rhythm, which gives them freedom to organize their time to study. Teachers can use all the material they find on social platforms to integrate their teaching, offering a structured experience to gradually build a scientific vision. Experimenting with social interaction in cooperative learning pedagogies also improves students' achievements, involving cognitive development and more effective learning [21].

Assessing the effectiveness of informal learning strategies is crucial for understanding their impact on motivation, interest, and attitudes toward physics and STEM subjects [12,22]. While there is substantial research on the positive effects of informal and non-formal physics education in terms of pedagogical and psychological outcomes, there is a notable lack of studies on how these strategies influence cognitive and non-cognitive learning outcomes, with only a few exceptions [23]. The diversity of informal learning activities makes it difficult to identify common factors across all approaches, and long-term studies aimed at evaluating the sustained impact of these activities are complicated to implement [24]. To assess the efficacy of informal learning, both qualitative feedback (e.g., personal or local observations) and more formalized semi-quantitative or quantitative methods can be employed [12].

The integration of digital and social technologies in education plays a crucial role in bridging the gap between research and society, fostering the widespread and inclusive dissemination of scientific knowledge. The incorporation of interdisciplinary knowledge, methods, and techniques into science and physics curricula is essential to illustrate the evolving nature of science and provide students with innovative tools for learning. An interdisciplinary approach, which combines knowledge from various fields to create synergistic effects, is increasingly common in education, particularly in high schools (see [12] and references therein). By blending knowledge, techniques, and methods from diverse disciplines, science education can better reflect the dynamic, interconnected nature of scientific inquiry.

Interdisciplinary education, which integrates knowledge from multiple disciplines, offers numerous benefits for students, fostering a more comprehensive and holistic learning experience. Indeed, as noted in [25], interdisciplinarity can enhance cognitive development by encouraging students to approach problems from multiple perspectives, promoting critical thinking and analytical skills. This approach helps bridge gaps between academic knowledge and real-world applications, making learning more relevant and meaningful. In engineering education, for instance, Catz et al. [26] highlight how an interdisciplinary teaching approach, such as integrating electronic circuits with other engineering principles, improves student understanding and the application of complex concepts. Interdisciplinary learning also nurtures creativity, as students learn to synthesize ideas from various fields to generate innovative solutions. Moreover, compared to traditional discipline-specific courses, interdisciplinary education makes learning more meaningful by enabling students to link new concepts with prior knowledge [27,28].

Research has shown that interdisciplinary education can improve student engagement and motivation by offering more dynamic and varied learning experiences [27]. By connecting different domains of knowledge, students are encouraged to think more flexibly, enhancing their problem-solving skills and enabling them to transfer knowledge across contexts [28–31]. This is particularly evident in STEM education, where interdisciplinary strategies have been found to improve students' ability to apply theoretical knowledge in practical settings [32]. Moreover, the implementation of interdisciplinary strategies in STEAM (STEM plus Arts) education has been revealed as particularly efficient in the humanities to foster the learning of contemporary physics topics (e.g., gravitational waves), engaging and motivating students towards science [33].

Furthermore, interdisciplinary approaches can lead to the development of transferable skills such as collaboration, communication, and teamwork, which are essential in today's complex, interconnected world. Gerke [34] notes that teachers' perceptions of interdisciplinary education are positive, recognizing its potential to foster deeper learning and holistic development in students. However, as Davies and Devlin [35] caution, interdisciplinary teaching requires careful design to balance the integration of multiple disciplines without overwhelming students with cognitive overload.

Despite these challenges, interdisciplinary approaches promote an appreciation for diverse fields and facilitate the exchange of ideas across disciplinary boundaries [36]. Incorporating the history and philosophy of science into science education offers numerous advantages, including better preparation for future scientists and a deeper public understanding of the nature of science. Introducing elements of the philosophy of science into high school curricula can also help challenge misconceptions, promote conceptual understanding, and encourage critical thinking about the scientific method and the nature of scientific inquiry (see [12] and references therein). Nevertheless, traditional science education often fails to effectively integrate such interdisciplinary content into the classroom. Fundamental questions in physics are frequently omitted from standard curricula, not because they are irrelevant, but due to the challenges of fitting them into conventional educational structures. Digital technologies can play a pivotal role in enhancing this integration, helping students become well-rounded citizens capable of thinking across disciplines and global contexts [27].

Despite the growing body of research, there remains a lack of established methodologies for effectively incorporating digital technologies into informal and interdisciplinary learning environments for high school students. Previous studies have highlighted the challenges and limitations of measuring the efficacy of informal education on cognitive and learning outcomes, underscoring the need for further research to improve the implementation of these practices in everyday school teaching.

This study aims to address this gap by focusing on the use of digital technologies and social networks to facilitate the learning of contemporary physics in an interdisciplinary and online context. Specifically, it examines the online teaching of physics within the framework of the "Gravitas" project [12,36], coordinated by the Cagliari Division of the National Institute of Nuclear Physics (INFN). The project seeks to offer an innovative educational experience that integrates physics with history, philosophy, and science communication. By leveraging digital technologies and social media platforms, the project aims to introduce contemporary physics topics into high school classrooms through informal learning strategies. Its primary objective is to provide students with a broader understanding of the Universe by combining scientific content with historical and philosophical perspectives, thereby promoting a holistic view of science and its role in society. In this regard, we tried to address the following research questions.

1. RQ1: Is it possible to monitor students' learning of contemporary physics in an interdisciplinary scenario, even during outreach and informal learning activities?
2. RQ2: What is students' feedback on using digital technologies as a teaching/learning strategy in the science classroom?
3. RQ3: Is there any gender or class differences in the students' feedback?

In the following, we will briefly discuss the design of the activities and the educational methodology followed in constructing "Gravitas" activities. We will present class and gender results on a feedback questionnaire aimed to address the research questions cited above. An analysis of the project's learning outcomes concerning the production of texts by participants will also be shown. The research can give instructors a methodological tool to encourage them to bring these topics to their physics classes, using digital technologies in physics learning, introducing students to current trends in research, and improving their motivation, curiosity, and interest in physics.

2. Materials and Methods

2.1. The "Gravitas" Methodology

Activities during the "Gravitas" project were divided into two parts. In the first part (from December 2021 to April 2022), we organized a series of 16 online seminars titled "Nuovi Dialoghi sui Massimi Sistemi"—"New Dialogues Concerning the (Two Chief) World Systems," due to the pandemic. These seminars covered various topics related to physics, the history of science, philosophy, and science communication. The topics were eventually split between physics-related and non-physics-related content, with nine seminars dedicated to each. The macro topics included high-energy physics, gravitational waves (both physics-related), as well as the history of science, philosophy of science, communication of science, and sociology (all non-physics). Activities were organized with an innovative format: During each online seminar, two researchers from different fields of study (e.g., physics vs. philosophy, history of science, scientific communication) met with a moderator to informally discuss gravity and related phenomena, with the active participation of the public, specifically high school students. The videos were streamed live and recorded on the INFN Cagliari YouTube channel [37,38]. At the end of each seminar, researchers provided reading tips to encourage students to approach the project's contents further. The list of seminars and their respective topics can be found in Table 1.

Table 1. Topics of the online seminars and related numbers of posts written by students within the "Gravitas" project.

Topic	Number of Posts
1. High-energy physics 1.1 Dark matter; The dark Universe (cosmology) 1.2 Quantum mechanics 1.3 The Higgs bosons	40
2. Gravitational physics 2.1 Gravitational waves 2.2 Moon travels 2.3 Einstein Telescope 2.4 The future of gravity	18
3. History of science 3.1 History of 20th century physics 3.2 Galilei's revolution 3.3 Crisis and revolutions in physics	11

4. Philosophy of science 4.1 Matter according to philosophy 4.2 Epistemology of physics 4.3 Logics 4.4 Spacetime and quantum gravity	25
5. Communication 5.1 The language of science	9
6. Sociology 6.1 The social impact of science	3

The educational goal of the first part of the project was twofold. Firstly, we aimed to offer a new interdisciplinary perspective on contemporary physics, particularly on gravity-related topics. Secondly, the project sought to facilitate informal physics learning in an online environment. One of our goals was to enrich students' scientific knowledge in contemporary physics and philosophy and the history of science.

As a mandatory activity to conclude the project, students created materials such as social media posts, with one post per month (four posts in total on four different topics). The topics were based on what they had learned from the seminars. Students had the option of working individually or in groups. Each post followed a fixed structure: It included each author's name, their school type and year, one image, and a caption. The posts also required references (for both the images and the information in the text) and hashtags. This approach allowed students to manage their learning process by acting as science communicators, preparing materials to disseminate scientific knowledge on specific platforms and targeting specific audiences. At the end of the project, we used the students' posts to organize an art exhibition to showcase their work. The materials submitted were transformed into QR codes, which were arranged to represent selected constellations visible from the Northern Hemisphere (Sardinia) in September 2022, when the festival was held (see [27,28] for details; only in Italian).

2.2. The Sample

The rationale and the program of activities were formally described in a document sent via email to all secondary schools in the Sardinian territory and shared through the social media channels and websites of INFN Cagliari and our university. To participate in the activities, secondary schools had to apply by responding to the email and indicating a pair of teachers responsible for disseminating the project information within the school.

Concerning the first part of the project, 236 students (m = 128, f = 108) from 16 high schools in Sardinia (43 were 19 yo; 130 were 18 yo; 63 were 17 yo). Only 127 students (m = 72, f = 55; 111 from scientific, nine from humanities, and seven from artistic high schools) ultimately ended the project by writing the posts as discussed above. Among the entire sample, only 70 students (m = 42, f = 28; 10 were 19 yo—fifth year; 40 were 18 yo—fourth year; 20 were 17 yo—third year) answered the final questionnaire.

2.3. Measures and Analysis

The questionnaire, originally written in Italian, was administered via Microsoft Forms. At the conclusion of the first part of the project (April 2022), the organizers distributed the questionnaire link to students via email. We collected anonymous data from April to June 2022. During the data collection period, we sent multiple reminders via email to teachers participating to the project with their classes or students to obtain the maximum number of answers to the questionnaire. Participation was voluntary, with no incentives or penalties provided. Since the project activities also involved minors (16–18 years old), the contacted teachers gathered the informed consent of the students' parents, requesting permission to use the students' questionnaire responses for research purposes. Completion of the questionnaire and the consent form by students or their parents was not mandatory for participation in the activities. The teachers informed us that all participating students (or their parents) completed the informed consent form, agreeing to the use of the data collected through the questionnaire for research purposes. At the time the study was conducted, ethical approval of our research from our departments was not required.

Inspired by similar studies [32–35], we administered a self-report questionnaire to address our research questions and explore various topics related to the project's content and methodology. We identified five main domains, along with several specific items for investigation: motivation (26 items), interest (3 items), learning (14 items), feedback on the proposed themes and the implementation of our format in schools (9 items), and creative skills (5 items). For the motivation domain, we differentiated between physics (11 items) and philosophy (11 items), as these are the primary topics of the project. We also examined the overall impact of the project on students' motivation to study physics, philosophy, and science communication, as well as their engagement with the activities offered (4 items). Additionally, we assessed the extent to which students' interest in physics, philosophy, and science communication increased after participating in the "Gravitas" project (3 items). Another area of focus was feedback on content learning, which ranged from physics and philosophy to science communication (7 items) and students' perspectives on the nature of science (4 items). We evaluated student satisfaction with the project by exploring their interest in the topics, their pursuit of further personal study, and the extent to which the project met their learning needs (3 items). Our objectives also included gathering students' feedback on interdisciplinarity and the potential implementation of our methodology in school settings (4 items). We examined their attitudes towards using our YouTube videos as educational material for learning contemporary physics in school and incorporating communication tools (e.g., dialogues) to make lessons more interactive and engaging (5 items). Finally, we assessed how creativity—specifically, writing posts—affected students' learning and emotional engagement with the project's content (5 items). We conducted a final global qualitative measure to gauge overall project appreciation (1 item, see [12,36]).

Students responded using a 6-point Likert scale, ranging from 1 (completely disagree) to 6 (completely agree). The questionnaire, originally written in Italian, was administered via Microsoft Forms. At the conclusion of the first part of the project (April 2022), the organizers distributed the questionnaire link to the students via email. We collected anonymous data from April to June 2022. Participation was voluntary, with no incentives or penalties provided.

An item distribution analysis showed adequate values for univariate skewness (range from 0.03 to −1.28) and kurtosis (range from 0.12 to 1.55) for all items (see Section 3). Moreover, we examined factor structure (exploratory factor analysis, or EFA) and internal consistency (Cronbach's alpha) for all sections of the questionnaire. EFA models were estimated with a maximum likelihood estimator. To examine associations among the main domains, Pearson's correlation coefficients were computed. To determine if there were statistically significant mean differences based on gender, we conducted a multivariate analysis of variance (MANOVA). In Section 3, we will discuss both qualitative (means and standard deviations) and quantitative (F-statistic) findings for all domains and related items. All analyses were performed using Jamovi software, version 2.5.5.

Using formative evaluation methods [39], we qualitatively assessed students' learning levels for creative tasks, such as writing posts. These evaluations were based on the objectives of the activity, specifically to create texts for communicating scientific content on social networks. The goal was also to inform participants of the "GravitasFest" about the topics covered during the festival, which aligned with those of the "Gravitas" project. Evaluation criteria included coherence with the chosen topic, writing quality within the constraints of social media formats, creativity, and originality—particularly in the selection of accompanying images—and the ability to stimulate curiosity in the reader. Examples of some of the posts received are presented in Appendix A.

3. Results

3.1. Factor Analyses and Internal Consistency

We tested the psychometric properties of all dimensions included in the questionnaire (except interest in physics, philosophy, and social communications because they are single-item measures). All dimensions showed adequate unidimensional factorial structures and reliability. The range of standardized factor loadings, proportion of variance explained, and internal consistency values are reported in Table 2.

Table 2. Factor loadings, variance explained, and internal consistency for unidimensional solutions.

Questionnaire	Items	Factor Loadings	% Variance	α
Motivation in physics	11	0.58–0.82	55	0.93
Motivation in philosophy	11	0.59–0.87	54	0.92
Motivation in "Gravitas"	4	0.60–0.74	53	0.81
Learning	14	0.50–0.77	47	0.92
Feedback implementation	9	0.61–0.77	49	0.89
Feedback on writing	5	0.79–0.86	66	0.91

3.2. Correlations

A correlation analysis showed positive significant relationships among all investigated domains except for motivation in philosophy with motivation and interest in physics (see Table 3). It should be noted that the dimension related to the process of learning within the project is highly correlated with the motivation in the main topics of "Gravitas" (r = 0.79), and with the feedback on the implementation of the "Gravitas" methodology at school (r = 0.77) and on the post-writing activity (r = 0.80).

Table 3. Correlations among domains.

	1	2	3	4	5	6	7	8
1. Motivation in physics	-							
2. Motivation in philosophy	0.23	-						
3. Motivation in "Gravitas"	0.60 ***	0.46 ***	-					
4. Interest in physics	0.77 ***	0.01	0.60 ***	-				
5. Interest in philosophy	0.31 *	0.52 ***	0.69 ***	0.26 *	-			
6. Interest in social communication	0.32 **	0.32 **	0.72 ***	0.38 **	0.63 ***	-		
7. Learning	0.66 ***	0.39 ***	0.79 ***	0.70 ***	0.52 ***	0.59 ***	-	
8. Feedback implementation	0.54 ***	0.35 **	0.66 ***	0.57 ***	0.41 ***	0.30 *	0.77 ***	-
9. Feedback on writing	0.46 ***	0.32 **	0.71 ***	0.61 ***	0.58 ***	0.49 ***	0.80 ***	0.71 ***

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

3.3. Mean Differences

Concerning assumptions: Box's M-test for homogeneity indicated homogeneous covariance matrices across groups (χ^2 = 56.4, p = 0.12); the Shapiro–Wilk test of normality is significant, but univariate skewness values are adequate to all the items (see Tables 4–10).

The results of the MANOVA did not show a significant multivariate difference between male and female in the main domains (Wilks' lambda = 0.88, $F_{(9,60)}$ = 93, p = 0.51). A significant univariate difference between the two samples (F = 3.94, p = 0.05; η^2 = 0.06) only appeared for learning: male showed a higher value than female. Moreover, for students' feedback on the implementation of "Gravitas" methodology at school, there was a trend towards statistical significance (F = 3.76, p = 0.056; η^2 = 0.05), with male showing the highest means.

Tables 4–10 display means and standard deviations for the entire sample, sorted by gender. Table 4 reports the results for items related to motivation in physics; it should be noted that items 8 ("It is good to make efforts to study physics") and 4 ("Physics is interesting") had the highest global mean values, not only among the items related to motivation in physics, but also compared to all other items investigated. Table 5 presents the results for questions concerning motivation in philosophy. Item 9 ("To learn philosophy is important for my future career") had the lowest level of agreement among the participants. Table 6 displays the results related to motivation in the project's main topics, including physics, philosophy, science communication, and outreach activities. Table 7 shows the results concerning interest in physics, philosophy, and science communication. Table 8 provides results regarding students' feedback on their learning of content and the scientific methodology used within the project (e.g., the scientific method). Table 9 addresses students' feedback on implementing our methodology in school settings. In all these items, male students reported higher mean values than female students did. Lastly, Table 10 summarizes the results regarding students' feedback on writing posts.

Considering only the female sample, the low values related to the importance of learning physics and philosophy for their future career (see Items 9, Tables 4 and 5) and to the interest in science communication after the project (Item 3, Table 7, and Item 6, Table 8) should be noted. In turn, males showed a great interest in physics (see Items 4 and 8, Table 4) and, in common with females, a low value of the importance of philosophy for their future careers (see Item 9, Table 5).

For the sake of completeness, Appendix A includes examples of texts written by students on their preferred topics. These texts have been translated into English, with an effort to maintain the original level of writing as produced by the students in Italian.

Table 4. Descriptive statistics for the items related to motivation in physics.

Items	General Mean ± Std. Dev.	Gender (Mean ± Std. Dev.)	
	Global	**Male**	**Female**
1. I feel good in physics.	4.23 ±1.17	4.33 ± 1.07	4.07 ± 1.03
2. I like to study physics content.	4.59 ± 1.30	4.74 ± 1.17	4.36 ± 1.47
3. To me, it is important to have good grades in physics.	4.83 ± 1.12	4.98 ± 0.95	4.61 ± 1.31
4. Physics is interesting.	4.97 ± 1.15	5.14 ± 0.93	4.71 ± 0.93
5. Among my classmates, I am one of the best in physics.	4.44 ± 1.46	4.67 ± 1.37	4.11 ± 1.55
6. I expect to get good grades in physics.	4.67 ± 1.20	4.76 ± 1.18	4.54 ± 1.23
7. What I learn in physics is useful compared to other courses.	4.31 ± 1.17	4.38 ± 1.12	4.21 ± 1.26
8. It is good to make an effort to study physics.	4.96 ± 1.01	5.21 ± 0.81	4.57 ± 1.17
9. To learn physics is important for my future career.	4.17 ± 1.52	4.38 ± 1.41	3.86 ± 1.65
10. Physics is fun.	4.43 ± 1.25	4.57 ± 1.31	4.21 ± 1.13
11. To solve physics exercises is useful.	4.64 ± 1.04	4.67 ± 0.98	4.61 ± 1.13
Univariate skewness ranges from −0.03 to −1.28	4.57 ± 0.94	4.71 ± 0.82	4.35 ± 1.07

Table 5. Descriptive statistics for the items related to motivation in philosophy.

Items	General Mean ± Std. Dev.	Gender (Mean ± Std. Dev.)	
	Global	**Male**	**Female**
1. I feel good in philosophy.	4.41 ± 1.12	4.43 ± 1.13	4.39 ± 1.13
2. I like study philosophy content.	4.67 ± 1.22	4.88 ± 1.23	4.36 ± 1.16
3. To me, it is important to have good grades in philosophy.	4.70 ± 1.23	4.69 ± 1.30	4.71 ± 1.15
4. Philosophy is interesting.	4.87 ± 1.27	5.00 ± 1.30	4.68 ± 1.09
5. Among my classmates, I am one of the best in philosophy.	4.46 ± 1.30	4.45 ± 1.38	4.46 ± 1.07
6. I expect to get good grades in philosophy.	4.67 ± 1.21	4.52 ± 1.45	4.89 ± 0.88
7. What I learn in philosophy is useful compared to other courses.	4.04 ± 1.41	4.05 ± 1.31	4.04 ± 1.29
8. It is good to make an effort to study philosophy.	4.59 ± 1.28	4.71 ± 1.23	4.39 ± 1.23
9. To learn philosophy is important for my future career.	3.46 ± 1.41	3.48 ± 1.53	3.43 ± 1.35
10. Philosophy is fun.	4.19 ± 1.39	4.19 ± 1.53	4.18 ± 1.16
11. To solve philosophical exercises is useful.	3.84 ± 1.37	3.76 ± 1.54	3.96 ± 1.07

Univariate skewness ranges from −0.11 to −1.18	4.35 ± 0.98	4.38 ± 1.09	4.32 ± 0.80

Table 6. Descriptive statistics concerning motivation in the main topics of "Gravitas."

Items	General Mean ± Std. Dev.	Gender (Mean ± Std. Dev.)	
	Global	Male	Female
1. During the project, I felt motivated to study physics.	4.53 ± 1.27	4.69 ± 1.18	4.29 ± 1.38
2. During the project, I felt motivated to study philosophy.	4.21 ± 1.32	4.38 ± 1.36	3.96 ± 1.23
3. During the project, I felt motivated to study science communication.	4.13 ± 1.37	4.33 ± 1.46	3.82 ± 1.19
4. During the project, I felt motivated to actively participate in the project's activities.	4.19 ± 1.22	4.24 ± 1.30	4.11 ± 1.10
Univariate skewness ranges from 0.03 to −0.65	4.26 ± 1.03	4.41 ± 1.05	4.04 ± 0.99

Table 7. Descriptive statistics for the items related to interest in the project's topics.

Items	General Mean ± Std. Dev.	Gender (Mean ± Std. Dev.)	
	Global	Male	Female
After attending the project, my interest in the following fields increased.			
1. Physics	4.40 ± 1.29	4.52 ± 1.21	4.21 ± 1.40
2. Philosophy	4.06 ± 1.34	4.07 ± 1.44	4.04 ± 1.20
3. Science communication	4.13 ± 1.44	4.29 ± 1.49	3.89 ± 1.37

Table 8. Descriptive statistics for the items related to the process of learning within the project.

Items	General Mean ± Std. Dev.	Gender (Mean ± Std. Dev.)	
	Global	Male	Female
1. The project helped me in learning new content about physics.	4.41 ± 1.12	4.57 ± 1.04	4.18 ± 1.22
2. The project helped me in learning new content about philosophy.	3.87 ± 1.35	4.14 ± 1.43	3.46 ± 1.43
3. The project spurred me to ask further questions about physics.	4.53 ± 1.29	4.79 ± 1.02	4.14 ± 1.56
4. The project spurred me to ask further questions about philosophy.	4.06 ± 1.36	4.21 ± 1.32	3.82 ± 1.42
5. Thanks to the project, I was able to learn about new physics and philosophical themes (even unexpected ones).	4.57 ± 1.25	4.67 ± 1.34	4.43 ± 1.10
6. The project stimulated my interest in science communication.	4.01 ± 1.47	4.19 ± 1.45	3.75 ± 1.48
7. The project gave me insights into the correct way to communicate science.	4.41 ± 1.19	4.52 ± 1.21	4.25 ± 1.14
8. The topics of the project were interesting.	4.81 ± 0.94	4.98 ± 0.81	4.57 ± 1.07
9. The project encouraged me to further investigate the covered topics.	4.21 ± 1.24	4.40 ± 1.11	3.93 ± 1.39
10. The project met my learning needs on the topics covered.	4.29 ± 1.21	4.38 ± 1.25	4.14 ± 1.15
11. With the project, I was able to get in touch with the phenomena currently studied by the researchers.	4.64 ± 1.02	4.81 ± 1.02	4.39 ± 0.99
12. The project allowed me to understand the importance of collecting, analysing, and interpreting data.	4.34 ± 1.21	4.45 ± 1.19	4.18 ± 1.25
13. The project allowed me to understand how a scientific investigation is conducted.	4.26 ± 1.15	4.40 ± 1.15	4.04 ± 1.14
14. The experience with the project allowed me to understand how a scientist works.	4.40 ± 1.27	4.60 ± 1.19	4.11 ± 1.34
Univariate skewness ranges from −0.16 to −0.93	4.34 ± 0.86	4.51 ± 0.77	4.10 ± 0.94

Table 9. Descriptive statistics related to students' feedback on the implementation of "Gravitas" methodology at school. Significant means differences are in bold.

Items	General Mean ± Std. Dev.	Gender (Mean ± Std. Dev.)	
	Global	Male	Female
The way of participating in the activities and the format chosen to communicate science during the "Gravitas" project are useful for learning content at school.			
1. Online seminars	4.03 ± 1.35	4.29 ± 1.37	3.64 ± 1.25
2. Interactive dialogues with researchers	4.40 ± 1.33	4.64 ± 1.38	4.04 ± 1.20

3. Use of Mentimeter to engage with the audience	4.16 ± 1.18	4.29 ± 1.22	3.96 ± 1.10
4. YouTube live chats to interact with researchers	4.00 ± 1.38	4.02 ± 1.42	3.96 ± 1.35
5. Reading tips	4.23 ± 1.50	4.33 ± 1.63	4.07 ± 1.27
6. The topics covered during the project can be treated in the classroom	3.94 ± 1.34	4.12 ± 1.45	3.68 ± 1.12
7. I would also like to see physics and philosophy in an interdisciplinary way, as in the "Gravitas" project, in the classroom	4.60 ± 1.32	4.90 ± 1.36	4.14 ± 1.15
8. Gravitas seminars can be used in the classroom as educational material	4.11 ± 1.47	4.38 ± 1.43	3.71 ± 1.46
9. The communicative format of the seminars can also be used in the classroom to boost students' involvement in learning a subject	4.23 ± 1.43	4.00 ± 1.53	3.96 ± 1.23
Univariate skewness ranges from −0.12 to −0.70	4.19 ± 1.01	4.38 ± 1.01	3.91 ± 0.95

Table 10. Descriptive statistics related to students' feedback on the post-writing activity.

Items	General Mean ± Std. Dev.	Gender (Mean ± Std. Dev.)	
	Global	Male	Female
Writing the post:			
1. Was useful to better understand the topics covered during the project	4.46 ± 1.28	4.50 ± 1.50	4.39 ± 0.88
2. Allowed me to become more passionate about the topics covered	4.19 ± 1.25	4.31 ± 1.33	4.00 ± 1.12
3. Sparked my interest in the project	4.13 ± 1.31	4.26 ± 1.29	3.93 ± 1.33
4. Motivated me to carefully attend the seminars	4.23 ± 1.34	4.31 ± 1.41	4.11 ± 1.26
5. Made me feel involved in the project	4.13 ± 1.38	4.26 ± 1.43	3.93 ± 1.30
Univariate skewness ranges −0.21 to −0.92	4.23 ± 1.12	4.33 ± 1.18	4.07 ± 1.03

3.4. Learning

We gathered a total of 106 posts covering various topics, as detailed in Table 11. Of these, 54.71% (n = 58) were focused on physics content, while 45.29% (n = 48) pertained to non-physics content (refer to Table 1). The posts were contributed by 55 distinct groups, each consisting of students from the same academic year. The topics selected by students for their posts are illustrated in Figure 1. Figures 2 and 3 present the distribution of posts by student year and the breakdown of physics- and non-physics-related posts by year, respectively.

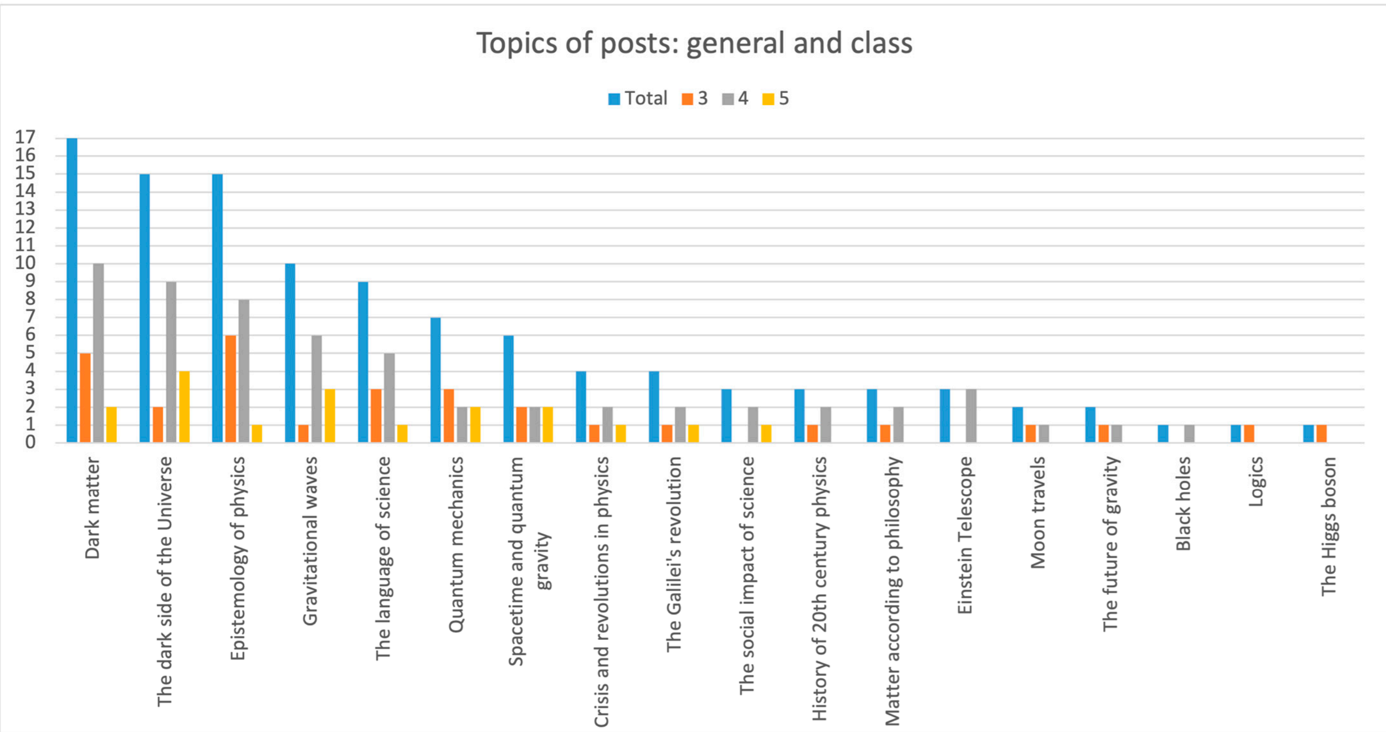

Figure 1. Number of posts for a given topic. In blue are the total number of choices; in orange, grey, and yellow are the choices divided by year, i.e., third, fourth, and fifth.

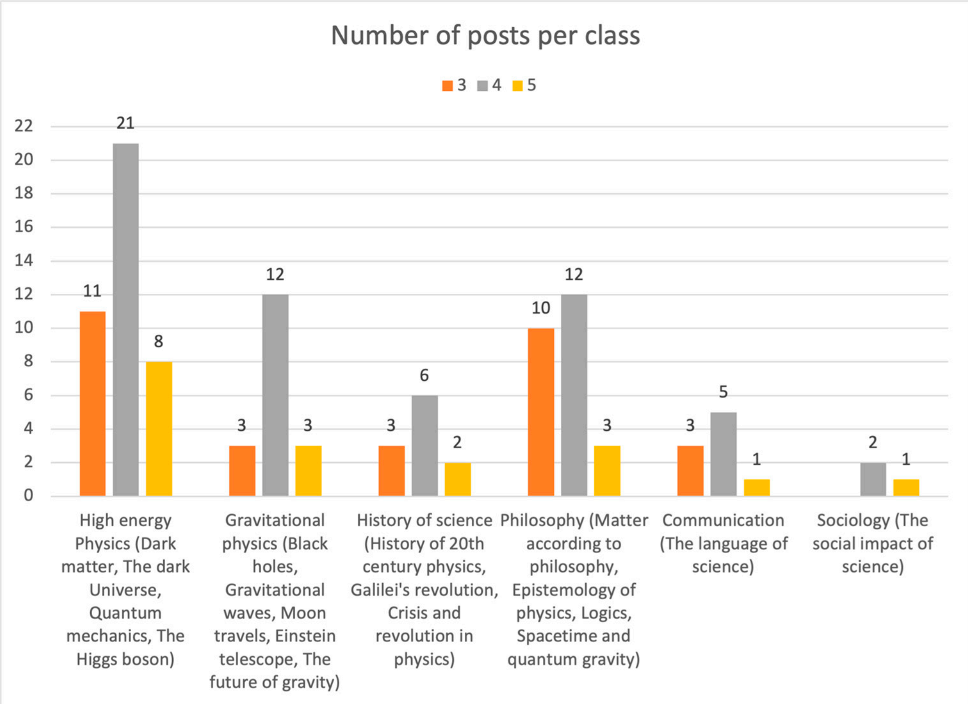

Figure 2. Number of posts grouped by category, divided by year.

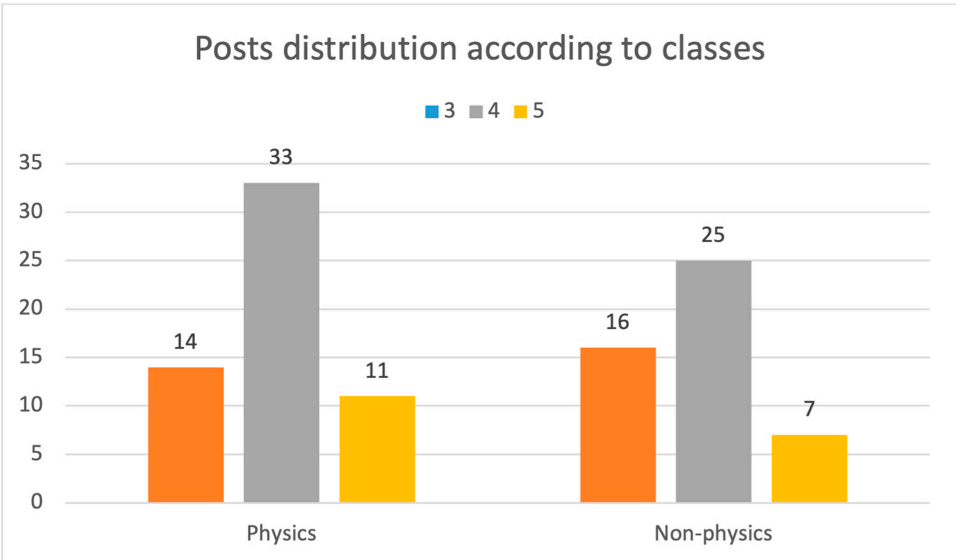

Figure 3. Number of posts related to both physics and non-physics contents, divided by year.

Table 11. The distribution of posts written by students among classes and number of members.

	3rd Year	4th Year	5th Year	Total
1 member	6	11	7	24
2 members	7	9	1	17
3 members	2	11	1	14
Number of groups	15	31	9	55
Number of contributions	30	58	18	106

4. Discussion

4.1. Questionnaire

Our analysis indicates a generally positive impact of the project on students' motivation towards physics, philosophy, and science communication. The data reveal that while means for physics-related content are slightly higher compared to other disciplines, items relating to the significance of studying philosophy for future careers showed the lowest overall mean. The lack of correlation between motivation for physics and philosophy was anticipated, given that the project predominantly focused on physics, and students were initially drawn to the project due to their interest in this subject. Philosophical arguments and science communication content were used by speakers to enhance students' engagement with these topics. Overall, students demonstrated a strong motivation to actively participate in the project's activities.

Regarding gender differences, no statistically significant differences appeared, but it should be noted that male students generally reported slightly higher means than female students across all items examined. In terms of learning outcomes, students expressed satisfaction with the project's design and methodologies. On average, the project was effective in helping students grasp new concepts in both physics and philosophy. Notably, higher mean scores were recorded in three specific areas: fostering curiosity and further inquiry, acquiring new physics knowledge, and learning philosophical tools for science communication. The project's methodology had a positive impact on learning. The seminars stimulated creativity and encouraged new questions about physics and philosophy, indicating the need for further investigation into the creative processes involved. Implementing a synchronous component following seminars could further explore this aspect.

Our methodological approach, which involved a comprehensive investigation of the Universe and a historical and physical reconstruction of scientific discoveries, successfully provided students with new tools for understanding their surroundings. This achievement aligns with the goals of physics education in informal learning contexts. The interdisciplinary nature of the "Gravitas" project, integrating physics, philosophy, and science communication, broadened students' perspectives on the nature of science. Students engaged with contemporary research and phenomena, gaining insights into scientific methods and expressing increased interest in physics, philosophy, and science communication. These findings corroborate other studies highlighting the importance of informal learning activities in enhancing students' interest and motivation in science [12,15,20,33]. Feedback on the project's methodology was positive, with students valuing the format and suggesting its potential for classroom application, particularly due to its interdisciplinary approach. Many students rated the format highly and proposed using the YouTube seminar as educational material for classroom discussions on physics and the philosophy of science. This aligns with previous research emphasizing the benefits of online learning materials in enhancing student engagement and motivation [20]. Gender-based results showed that males exhibited significantly more interest than females in the interdisciplinary aspects of physics and philosophy, both in the "Gravitas" project and in classroom settings.

4.2. Learning

Encouraging students to engage in creative writing through posting significantly impacted their development across various domains. The data indicate that this activity enhanced their enthusiasm for both physics and the project's themes while also deepening their learning experience. Feedback from students, provided in the final open-ended section of the questionnaire, highlighted the crucial role of the personal reinterpretation of content in solidifying their scientific knowledge. These findings align with previous research [33,35,36], which suggests that such activities stimulate students' interest in physics by fostering creativity and the personal reinterpretation of concepts, tailored to the activity's specific features.

The presence of a creative objective within the project, such as writing a post, appears to have contributed to a tangible sense of involvement. Additionally, knowing that their work might be featured in a social campaign for the "Gravitas" festival (later transformed into an interactive artwork exhibition for practical reasons) likely bolstered their motivation and sense of project participation.

Overall, the mean scores were higher for physics-related content. However, the range of topics chosen by students in the third and fourth years covered the full spectrum of project options. Third-year students tended to focus on non-physics topics, while fourth- and fifth-year students favored physics-related content, particularly high-energy physics. Topics such as dark matter and cosmology were the most popular, followed by gravitational subjects. Non-physics posts were often related to physics, such as the philosophy of physics and the history of 20th-century physics. This trend may be attributed to the scientific high school curriculum, where third-year students, having only recently begun studying physics, are more familiar with historical and philosophical aspects. As students advance to their final year, their interest in physics deepens, leading to specialization in specific topics, as illustrated in Figures 2 and 3. These results suggest that interdisciplinary approaches in education can help present physics as a cohesive body of knowledge, thereby stimulating critical thinking skills [40–52].

In evaluating students' learning outcomes, we assessed their work based on the criteria outlined in the previous section. Generally, while students conveyed information learned during the project, many lacked personal and critical reinterpretation of the content. Errors were present in a few cases, such as some groups mistakenly attributing the role of dark energy to dark matter and vice versa, as per the standard cosmological model. Additionally, inaccuracies regarding gravitational wave physics, particularly the historical context of discoveries, were noted, possibly due to the advanced nature of General Relativity relative to the standard scholar curriculum. This underscores the need for further educational activities in this area. While the groups successfully communicated science and related topics, some failed to meet specific communication goals, opting instead to present data. The posts would benefit from a clearer structure (introduction, development, and conclusion) and more emphasis on engaging and intriguing aspects of physics. Physics teachers could enhance students' soft skills, such as writing and communication, through targeted educational interventions. These skills are crucial both academically and beyond. Writing about science not only supports learning and personal reinterpretation, but also fosters creativity. For illustrative purposes, we include a post from a fourth-year group on gravitational waves, showcasing their approach to the topic.

> *"In its immensity, the Universe hides most of its characteristics; therefore, we know about 5% of it, and the rest is called the "dark side". The dark side constitutes a considerable part of our Universe, but we do not know what it is composed of as it cannot be detected through Einstein's theory of relativity, which relates the masses of objects to the light they absorb. The 5% of the known universe is made of ordinary, i.e., luminous, matter, but if we consider the "unknown" part, we know that 25% is made of dark matter, which does not absorb or emit any light; the remaining 70% is dark energy which does not have a form, therefore not reducible to particles, and which is in accelerated expansion. How can we study the Universe? Considering the tremendous amount of material still to be discovered and analyzed and the need for costly instruments, the collaboration of all research experts is necessary. However, it must be considered that some of the dark matter may not be knowable as its signals cannot be detected. Thanks to projects such as the Moonlight experiment, artificial satellites are used, which can further test the theory of relativity and continue to study the Moon and the phenomena to which it is subject, for example, the formation of craters due to meteorite impacts. It is also hoped that our satellite could one day help us make longer space journeys with the aim of reaching Mars."*

In this case, starting from a general introduction on the dark side of the Universe, made by dark energy and dark matter components, the reader is led to a question on how to study the Universe ("How can we study the Universe?"). The focus then moves to a specific experiment related to the scientific investigations of the Moon (the Moonlight experiment) and space journeys. It will test General Relativity on local scales in the Solar System. In contrast, dark matter and dark energy phenomena concern the large-scale properties of the Universe. Some excellent posts reaching the project goal are listed in Appendix A. They are aimed at social networks, as requested: They are short, well-written, and able to inform people about current research topics and challenges in the topic they deal with, stimulating curiosity in the reader. The choices of hashtags to link the text to trends and topics in social networks adequately represent their topics. Finally, considering the entire sample, we noticed that posts written by students attending the third-year class reached the goal of the requested tasks more efficiently than their older peers.

5. Conclusions

This paper investigates how the interdisciplinary, online, and informal learning initiative known as "Gravitas" can enhance the study of contemporary physics in high school settings. Coordinated by the Cagliari Division of INFN and the Physics Department of the University of Cagliari, the project integrates physics and the philosophy of science with science communication tools to provide participants with a cohesive understanding of these fields. The paper details the project's structure, pedagogical approach, and methodology employed to implement this interdisciplinary framework.

Addressing Research Question 1 (RQ1), we developed two tools to assess students' learning of contemporary physics within this informal, interdisciplinary context: a research questionnaire and a formative evaluation of texts. The questionnaire yielded positive feedback regarding students' appreciation of our methodology in introducing contemporary physics topics to the classroom, noting its effectiveness in enhancing their motivation and interest. The formative evaluation corroborated these findings, with students acknowledging the methodology's success in stimulating their scientific creativity and encouraging their participation in the project.

Regarding Research Question 2 (RQ2), the use of digital technologies to complement formal curricula was viewed positively. Seminars and, notably, the format of online interactive dialogues with researchers were particularly well-received. For students in their final year of high school, the interdisciplinary approaches offered by the project are considered valuable both as preparation for their final exams and as a foundational component of their future academic pursuits.

Our analysis corroborates previous findings in Physics Education Research (PER) regarding the necessity of evaluating the effectiveness of informal learning activities. We collected both qualitative and quantitative data to assess the impact of our methodology on high school students' learning, motivation, enthusiasm, and interest in contemporary physics. Additionally, we gathered critical feedback from students about incorporating specific activities into classroom lessons to enhance engagement and improve the learning process. These activities included using online seminars as educational material, writing posts, and reinterpreting content in their own words, as well as the interdisciplinary nature and format of our seminars.

Regarding motivation, the data revealed insights into how our activities influenced students' motivation and identified which aspects had the most significant impact. This information could be useful for adjusting and strengthening parts of the project to better align with students' interests and learning needs in physics. For instance, students expressed a desire for more active participation in discussions and direct interaction with researchers beyond what was possible through Mentimeter and YouTube live chats.

In terms of gender differences (RQ3), although not significantly, males reported higher mean scores across all items, indicating greater overall appreciation of the project compared to their female counterparts. However, female groups performed better in writing posts. Our analysis, which focused on posts, also suggested that students in third year performed better than their peers in terms of post quality. Implementing small group structured interviews could be helpful to deeper investigate gender differences in our findings. We left this investigation for future research.

The study's results are promising, suggesting that digital technologies can effectively support the interdisciplinary learning of contemporary physics in informal settings. The use of these technologies did not adversely affect students' motivation or interest in the topics, reaffirming that the impact on learning outcomes is more closely related to the quality of teaching rather than the technological tools used [9,10]. It would also be interesting to find out whether the proposed holistic picture of physics leads to a better understanding of at least modern and contemporary physics. The writing activity (social posts) was intended to achieve this educational goal, and the results are encouraging in this direction. The use of social media posting appears to have been promising in its implementation during the project. It opens the possibility to implement our methodology not just with science students, but with all students in general moving towards less 'silo-based' practice in high schools. A longer in-class implementation conducted with smaller samples acting as control group could help us investigate this issue. These studies are left for future investigations.

The questionnaire provided valuable feedback on our pedagogical approach, offering insights into potential improvements aimed at enhancing students' understanding of contemporary topics and increasing their engagement. However, several limitations of the study should be noted. Notably, only half of the initial participants contributed to the project by posting content, and only one-third completed the final questionnaire. This response rate must be considered when assessing the effectiveness of the informal learning activities. To increase participation, we sent multiple follow-up requests to teachers via email during the data collection period; however, only a small number responded by completing the questionnaire. This low response rate may be attributed to a cultural aspect within our country, where studies of this type are not yet common. To address this issue in future research, a more collaborative approach involving researchers and teachers—such as engaging teachers in the design of the activities—could help mitigate this problem.

Additionally, the use of a categorical questionnaire limited the depth of our findings. While the internal consistency of the questionnaire was high, there is no evidence to suggest that its construct and criterion validity were assessed. To establish these aspects, further data collection would be necessary, such as through small group interviews to compare and validate our results. This remains an avenue for future research and further development of the project.

Moreover, the study did not monitor the mid- and long-term effects of the project on specific learning domains, which is a common challenge in informal learning contexts. Despite these limitations, we plan to expand our sample size in future iterations of the study in order to gather more comprehensive data. This will allow us to better understand the impact of our pedagogical methods on students' motivation, perceptions, and interest in contemporary physics, as well as in the history and philosophy of science.

Author Contributions: Conceptualization, M.T. and W.M.B.; methodology, M.T.; validation, D.F.; formal analysis, M.T. and D.F.; investigation, M.T. and A.S.; resources, M.T, W.M.B. and V.F.; data curation, M.T.; writing—original draft preparation, M.T.; writing—review and editing, M.T., A.S., D.F., R.S., V.F., and W.M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data cannot be made publicly available upon publication because no suitable repository exists for hosting data in this field of study. The data that support the findings of this study are available from the authors upon reasonable request.

Acknowledgments: We are grateful to all the faculty, teachers, and students who helped us with the study. We also thank the anonymous referees who helped us in improving the quality of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Here we list some of the well-written posts satisfying the criteria discussed in the paper.

Topic: Gravitational waves
Group: One member, fifth class
Title: The gravitational waves

The discovery of gravitational waves was one of the rare successes in scientific research to have thrilled crowds of ordinary people. Their story begins in 1916 when Albert Einstein hypothesized their existence and gave them a first definition: "They are fluctuations that are produced in the curvature of spacetime, and which propagate like waves moving away from the point of origin." The phenomenon in question is very similar to what happens when a boat turns on its engine and generates waves in the water, with the immense difference that the gravitational waves are generated by celestial objects of which we still know extremely little, such as black holes. These celestial bodies possess such an intense gravitational force that they do not even let light escape, and neutron stars are highly compact stellar bodies composed of degenerate matter. The first confirmations of Einstein's thesis came only a century later when, in February 2016, a scientific article was published, resulting from the collaboration between the LIGO and VIRGO interferometers, concerning the detection of two black holes with a mass equal to approximately 30 solar masses which they merged more than 1.3 billion light years from our planet; from that moment the number and frequency of recording of gravitational waves continued to increase until reaching 90 observations. The question becomes quite interesting if we consider the possibilities for the study of gravitational waves soon, projects such as the Einstein Telescope, with which Sardinia could obtain an important role in astronomical research, or the Lunar Gravitational-Wave-Antenna (LGWA). This project aims to build an interferometer on the lunar surface in conjunction with man's return to the Moon with the Artemis missions.

Hashtags: #Gravitas #INFN #Physics #Gravity #Gravitationalwaves #LIGO #VIRGO #EinsteinTelescope #LGWA #Artemis

Topic: The Galilei's revolution
Group: One member, fourth class
Title: The Galilei's revolution

Why, almost 460 years after his birth, do we still study a figure like Galileo Galilei? Focusing on how Galileo is studied in physics, history, and philosophy at school is necessary. Whoever answers the opening question by saying that it is studied for its discoveries or for the notional innovations it introduces into physics is wrong, or at least sees only a marginal aspect of the revolution that Galileo opened between the second half of the 1500s and the first half of 1600. You certainly won't fall into error if you illustrate the notions that Galileo materially discovered, such as the Medici Planets (the four moons of Jupiter), the imperfection of the lunar surface, the phases of Venus, and so on, but the real reason why we study Galileo is because he is a revolutionary; in physics but more generally in science, after Galileo nothing remains as before. One of the most significant innovations he brings to scientific thought is the intrinsic link, which he shapes, between reality and mathematics. He will go so far as to write that analyzing nature without giving a mathematical model is useless. All aspects, even the most diverse, from biology to computer science, of modern science are based on this simple thought, giving a mathematical basis to reality, and studying what surrounds us through quantitative and non-qualitative aspects. We should remember that Galileo lived in a period in which Aristotelian science and the principle of the authority of the Catholic Church reigned supreme. Trying to wrest from religion the power that he wanted to entrust to something as practical and not very dogmatic as mathematics was so revolutionary that it caused fear, which soon turned into repression and condemnation.

Hashtags: #Gravitas #INFN #Galileo #classicalphysics #scientificrevolution

Topic: Dark matter
Group: Three members, third class
Title: The dark matter

Until the first half of the 1900s, scientists believed that almost all the mass of the Universe resided in the stars; today, however, we know that these constitute only a negligible percentage of cosmic matter (around 4%). The remaining part of the mass of the Universe is not visible, and this missing mass is called Dark Matter. Furthermore, scientists think that alongside Dark Matter, there is a particular form of energy (known as Dark Energy), which, according to Einstein's equivalence principle, is capable of accounting for most of the mass of the Universe. The astronomer's and astrophysicists' observations of stars, galaxies, and galaxy clusters gave rise to the idea that the Universe had much more mass than was visible. Newton's law of universal gravitation follows that in a gravitational system such as that of a galaxy, the speed of the stars found in the region outside the nucleus must decrease as the distance increases. On the contrary, observations on hundreds of galaxies showed that the speed of stars far from the nucleus was much more significant than expected and did not decrease with distance. The latter can only be explained if we assume that the galaxy contains invisible and non-concentrated matter in the nucleus, whose gravitational attraction is responsible for the motion of the stars. Dark matter, as the name suggests, has never been directly observed until now. Therefore, even after the new measurements, the dispute between dark matter and alternative theories of gravity is not yet over.

Hashtags: #darkmatter #mistery #universe #INFNCagliari

Topic: Epistemology of physics
Group: One member, third class
Title: Physics, what science are you?

Every day, we ask ourselves many questions, but have we ever wondered what physics is? Answering with a concrete definition might seem simple. Still, it is very complex, as it is not easy to accurately define what science it is. If we look up the definition of the word "physics", it will be described as "natural science in the broadest sense". Physics was born to study natural phenomena, i.e., all the events that can be defined, quantified, or measured through appropriate physical quantities, to establish principles and laws regulating the interactions between the amounts and their variations. Physics describes how the world works, and by studying it, we discover the invisible laws of the universe; it deals with everything that surrounds us and tries to give meaning and a rational explanation to the phenomena that happen, observing the world around us. Physics and science are rarely exclusively individual studies attributed to a "single genius". Still, instead, we must consider it as a collective process because the concepts are shared concepts. We often spontaneously associate a single scientist with physical principles; think of Einstein's General Relativity, Newton's gravitational force, or Maxwell's electromagnetism. However, many scientists of the past, such as Einstein, referred to studies carried out by other people in the past, modifying or perfecting them; therefore, science would appear to be a collective enterprise. Nowadays, to complete his project, a scientist needs the collaboration of other scientists, physicists, engineers, and theorists. Science should be considered a collective process and, therefore, recognize the work of many people.

Hashtags: #physics #science #community #gravitas #INFN

References

1. Bianconi, G. Interdisciplinary and physics challenges of network theory. *Europhys. Lett.* **2015**, *111*, 56001.
2. Higgins, K.; Huscroft-D'Angelo, J.; Crawford, L. Effects of Technology in Mathematics on Achievement, Motivation, and Attitude: A Meta-Analysis. *J. Educ. Comput. Res.* **2019**, *57*, 283–319.
3. Broadbent, J.; Poon, W.L. Self-regulated learning strategies & academic achievement in online higher education learning environments: A systematic review. *Internet High. Educ.* **2015**, *27*, 1–13.
4. Hill, M.; Sharma, M.D.; Johnston, H. How online learning modules can improve the representational fluency and conceptual understanding of university physics students. *Eur. J. Phys.* **2015**, *36*, 045019.
5. Luksic, P.; Horvat, B.; Bauer, A.; Pisanski, T. Practical E-Learning for the Faculty of Mathematics and Physics at the University of Ljubljana. *Interdiscip. J. E-Ski. Lifelong Learn.* **2007**, *3*, 73–83.
6. Demirci, N. Web-based vs. paper-based homework to evaluate students' performance in Introductory physics courses and students' perceptions: Two years experience. *Int. J. E-Learn.* **2010**, *9*, 27–49.
7. Sulaiman, F. The effectiveness of PBL online on physics students' creativity and critical thinking: A case study at University Malaysia Sabah. *Int. J. Educ. Res.* **2013**, *1*, 1–18.
8. Vo, H.M.; Zhu, C.; Diep, N.A. The effect of blended learning on student performance at course-level in higher education: A meta-analysis. *Stud. Educ. Eval.* **2017**, *53*, 17–28.
9. Higgins, S.; Xiao, Z.; Katsipataki, M. *The Impact of Digital Technology on Learning: A Summary for the Education Endowment Foundation*; EEF—Education Endowment Foundation: London, UK, 2012.
10. Education Endowment Foundation Teaching & Learning Toolkit: Digital Technology (2019). Available online: https://educationendowmentfoundation.org.uk/education-evidence/evidence-reviews/digital-technology-2019?utm_source=/education-evidence/evidence-reviews/digital-technology-2019&utm_medium=search&utm_campaign=site_search&search_term=Digital%20Technology (accessed on 29 August 2024).
11. Chauhan, S. A meta-analysis of the impact of technology on learning effectiveness of elementary students. *Comput. Educ.* **2017**, *105*, 14–30.
12. Tuveri, M.; Fadda, D.; Steri, A.; Stefanizzi, R.; Gabriele, F.; Vivanet, G.; Bonivento, W.; Carbonaro, C.M.; Fanti, V. Promoting the learning of modern and contemporary physics in high schools in informal and non-formal contexts. *Nuovo C. C* **2023**, *46*, 210.
13. Simis, M.J.; Madden, H.; Cacciatore, M.A.; Yeo, S.K. The lure of rationality: Why does the deficit model persist in science communication? *Public Underst. Sci.* **2016**, *25*, 400–414.
14. Trench, B. Towards an Analytical Framework of Science Communication Models. In *Communicating Science in Social Contexts*; Cheng, D., Claessens, M., Gascoigne, T., Metcalfe, J., Schiele, B., Shi, S., Eds.; Springer: Dordrecht, The Netherlands, 2008.
15. Tuveri, M.; Serra, M.; Gola, E. Teaching, Communication, and Dissemination for Society. In *New Challenges and Opportunities in Physics Education, Challenges in Physics Education*; Streit-Bianchi, M., Michelini, M., Bonivento, W., Tuveri, M., Eds.; Springer: Cham, Switzerland, 2023; pp. 145–157.
16. Lee, S.C.; Lee, Z.W.; Yeong, F.M. Using social annotations to support collaborative learning in life sciences module. In Proceedings of the ASCILITE 2019—Conference Proceedings—36th International Conference of Innovation, Practice and Research in the Use of Educational Technologies in Tertiary Education: Personalized Learning, Diverse Goals, One Heart, Singapore, 2–5 December 2019.
17. Garrido, G.; Guthrie, M.W.; Chen, Z. How is students' online learning behavior related to their course outcomes in an introductory physics course? In Proceedings of the Physics Education Research Conference, Provo, UT, 24–25 July 2019; pp. 165–171.
18. Bolliger, D.U. Key factors for determining student satisfaction in online courses. *Int. J. E-Learn.* **2004**, *3*, 61–67.
19. Kortemeyer, G. Work Habits of Students in Traditional and Online Sections of an Introductory Physics Course: A Case Study. *J. Sci. Educ. Technol.* **2016**, *25*, 697–703.
20. Tuveri, M.; Zurru, A.; Fadda, D.; Saba, M. Online learning mediated by social teaching platforms: An experience from a flipped undergraduate physics course in renewable energies. *Eur. J. Phys.* **2022**, *43*, 055703.
21. Piaget, J. *Origin of Intelligence in the Child, Selected Works*; Routledge: London, UK, 2013; Volume 3.
22. Bandura, A. On the functional properties of perceived self-efficacy revisited [Editorial]. *Journal of Management* **2012**, *38*, 9–44.
23. Ward, T.W.; Herzog, W.A. *Effective Learning in Non-Formal Education*; Michigan State University: East Lansing, MI, USA, 2013.
24. Izadi, D.; Willson, J.; Finkelstein, N.; Fracchiolla, C.; Hinko, K. Towards mapping the landscape of informal physics educational activities. *Physical Review Physics Education Research* **2022**, *18*, 020145.
25. Lattuca, L.R.; Voight, L.J.; Fath, K.Q. Does interdisciplinarity promote learning? Theoretical support and researchable questions. *The Review of Higher Education* **2004**, *28*, 23–48.

26. Catz, B.; Kolodny, A.; Gero, A. Promoting engineering students' learning: An interdisciplinary teaching approach of electronic circuits. *Int. J. Eng. Educ.* **2023**, *39*, 208–218.
27. Jantsch, E. Towards interdisciplinarity and transdisciplinarity in education and innovation. In *Interdisciplinarity: Problems of Teaching and Research in Universities*; Apostel, L., Berger, G., Briggs, A., Michaud, G., Eds.; OECD: Paris, France, 1972; pp. 97–121.
28. Scott, T.; Hazari, Z.; Potvin, G. Interdisciplinary Thinking and Physics Identity. In Proceedings of the Physics Education Research Conference, Portland, OR, USA, 17–18 July 2013.
29. Borrego, M.; Newswander, L.K. Definitionf of interdisciplinary research: Toward graduate-level interdisciplinary learning outcomes. *The Review of Higher Education* **2010**, *34*, 61–84.
30. Field, M.; Lee, R.; Field, M.L. Assessing interdisciplinary learning. *New Direction for Teaching and Learning* **1994**, *58*, 69–84.
31. Spelt, E.J.H.; Biemans, H.J.A.; Tobi, H.; Luning, P.A.; Mulder, M. Teaching and Learning in Interdisciplinary Higher Education: A systematic review. *Educ. Psychol. Rev.* **2009**, *21*, 365.
32. Gao, X.; Li, P.; Shen, J.; Sun, H. Reviewing assessment of student learning in interdisciplinary STEM education. *Int. J. STEM Educ.* **2020**, *7*, 24.
33. Tuveri, M.; Steri, A.; Fadda, D. Using storytelling to foster the teaching and learning of gravitational waves physics at high-schools. *Physics Education* **2024**, *59*, 045031.
34. Gerke, A. Interdisciplinary Education in the Elementary Curriculum: Exploring Teacher Perceptions and Practices. A research paper submitted in conformity with the requirements For the degree of Master of Teaching Department of Curriculum, Teaching and Learning Ontario Institute for Studies in Education of the University of Toronto, ON, Canada, April 2017.
35. Davies, M.; Devlin, M.T. *Interdisciplinary Higher Education: Implications for Teaching and Learning*; Centre for the Study of Higher Education: Melbourne, Australia, 2007.
36. Tuveri, M.; Fadda, D.; Fanti, V.; Bonivento, W. When gravity meets philosophy again: The "Gravitas" project. In Proceedings of the Science (ICHEP2022), Bologna, Italy, 6–13 July 2022; p. 392.
37. Available online: https://www.youtube.com/playlist?list=PL94cdNBLY9XqD3V_YqEjVyQPXmspf2-k8 (accessed on 29 August 2024).
38. Available online: https://dark.infn.it/raccontare-la-gravita/ (accessed on 29 August 2024).
39. Furtak, E.M. *Formative Assessment for 3d Science Learning*; Teachers College Press: New York, NY, USA, 2023.
40. Etkina, E.; Karelina, A.; Murthy, S.; Ruibal-Villasenor, M. Using action research to improve learning and formative assessment to conduct research. *Phys. Rev. Stud. Phys. Educ. Res.* **2009**, *5*, 010109.
41. Teixera, E.S.; Greca, I.M.; Olival, F.J. The History and Philosophy of Science in Physics Teaching: A Research Synthesis of Didactic Inventions. *Sci. Educ.* **2012**, *21*, 771.
42. Koetter, M.; Hammann, M. Controversy as a Blind Spot in Teaching Nature of Science. *Sci. Educ.* **2017**, *26*, 451–482.
43. Pronskikh, V.; Galina, V.S. Expert Text Analysis in the inclusion of history and philosophy of science in higher education. *Sci. Educ.* **2022**, *31*, 961–975.
44. Henriksen, E.K.; Bungum, B.; Angell, C.; Tellefsen, C.W.; Frågåt, T.; Vetleseter Bøe, M. Relativity, quantum physics and philosophy in the upper secondary curriculum: Challenges, opportunities and proposed approaches. *Phys. Educ.* **2014**, *49*, 678.
45. Rizos, I. Teaching scenarios and their role in the interdisciplinary approach. Case study: The Minkowskian metric. In Proceedings of the First Congress of Greek Mathematicians, Athens, Greece, 25–30 June 2018; pp. 216–227.
46. Henke, A.; Höttecke, D. Physics teachers' challenges in using history and philosophy of science in teaching. *Sci. Educ.* **2015**, *24*, 349–385.
47. Chan, S.C. The interplay between physics and philosophy in undergraduate education. *J. NUS Teach. Acad.* **2014**, *4*, 18–26.
48. Pan, R.; Sinha, S.; Kaski, K.; Saramäki, J. The evolution of interdisciplinarity in physics research. *Sci. Rep.* **2012**, *2*, 551.
49. Pluchino, A.; Burgio, G.; Rapisarda, A.; Biondo, A.E.; Pulvirenti, A.; Ferro, A.; Giorgino, T. Exploring the role of interdisciplinarity in physics: Success, talent and luck. *PLoS ONE* **2019**, *14*, e0218793.
50. Rinia, E.J.; van Leeuwen, T.N.; van Vuren, H.G.; van Raan, A.F.J. Influence of interdisciplinarity on peer-review and bibliometric evaluations in physics research. *Res. Pol.* **2001**, *30*, 357–361.
51. D'Este, P.; Robinson-García, N. Interdisciplinary research and the societal visibility of science: The advantages of spanning multiple and distant scientific fields. *Res. Pol.* **2023**, *52*, 104609.
52. Larivière, V.; Gingras, Y. On the relationship between interdisciplinarity and scientific impact. *J. Am. Soc. Inf. Sci.* **2010**, *61*, 126–131.