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Promoting the learning of modern and contemporary physics in high schools in informal and non-formal contexts

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Summary. — In this paper, we introduce active learning strategies developed by the Educational Division of the Physics Department of the University of Cagliari to promote the learning of modern and contemporary physics (*e.g.*, general relativity, particle physics, cosmology, and related topics) in high schools in informal and non-formal contexts. We discuss their features and potential role in facilitating science and physics instruction by integrating pedagogical theory and education research. We illustrate our theoretical framework and the methodologies we implemented to design specific educational strategies —and the evaluation of their effectiveness— to improve motivation, curiosity, and interest in modern and contemporary physics, as well as bring these topics more extensively to high schools. Finally, examples of the proposed educational activities are presented and their implications in informal and non-formal contexts are discussed.

1. – Introduction

Learning is an active and non-linear process centered on the learner, which connects their past, present, and future knowledge [1, 2]. Learners develop their knowledge and construct meaning in interaction with the social context and environment, using active engagement with the world [3, 4]. It is a process that lasts a lifetime, from childhood to adulthood, which constantly leads us to learn new concepts, promoting our culture and knowledge [5].

According to the standard educative system classification proposal, learning can occur in three different education contexts: formal, non-formal, and informal [6]. While there

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(*) Corresponding author. E-mail: `matteo.tuveri@ca.infn.it` are several definitions for them in the literature, in this paper, we assume that formal education corresponds to a systematic, organized education model, structured and administered according to a given syllabus, with a set of laws and norms presenting a rigid curriculum in terms of objectives, content, and methodology [6-8]. Learning happens at the high school, college, or graduate level [9]. It is considered intentional. Learning is the goal of all the activities learners engage in. Learning outcomes are measured by tests and other forms of assessment [4, 6].

When one or more of these features are missing, we assume to be in a non-formal education system. In this case, educational activities often occur in a formal learning environment not formally recognized within a curriculum or syllabus framework (workshops, symposia, extracurricular courses, seminars) [10]. The non-formal contexts have a lower degree of organization and a more flexible structure than formal ones. Usually, non-formal education is provided by specialists in different areas, not necessarily having a certified pedagogical background. Instructors build learning strategies considering learners' interests, often promoting self-evaluation tasks [11]. In non-formal learning, learning goals are not defined according to any formal plan [12].

Even if formal environments are recognized as the ones deputed for education, learning is a process that occurs in every instance of our lives. Students spend most of their learning time in informal contexts, out-of-school time, and outdoor activities, such as their families, relationship, science outreach labs, visits to museums, summer camps, and consumption of science-related media on social networks, tv shows, and newspapers [13-29]. These are examples of informal education environments, and their role in education is increasingly recognized at institutional, scholarly, and academic levels [2,30,31]. Informal learning differs from formal learning because it is structurally non-didactic; it builds on the learner's initiative, interest, or choice (rather than resulting from external demands or requirements) and does not involve assessment external to the activity [9, 32-34].

Active learning strategies are at the core of informal and non-formal learning education [35]. Active learning strategies are those pedagogical methods that include interactive components during lectures where students learn more by doing [36-38]. Generative learning is at the basis, where the focus is on cognitive rather than behavioral processes [39]. Active learning strategies are implemented in this educational system to encourage students' autonomy and participation in their learning process, giving them a leading role and, according to a constructivist perspective [1], placing the teacher not as a mere transmitter of knowledge but as a facilitator or guide of that learning [40]. Active learning promotes their creativity, helping them develop the skills that increasingly determine their future employability and personal development, increasing their STEM performances [41]. Constructivism-based active learning approaches are well recognized as effective in science teaching and learning, reporting positive learning outcomes for students in achievement, enthusiasm, ownership, and scientific skills development [42-45]. However, despite the general recognition that constructivist theories and practice have had in the educational literature, evidence about the efficacy of these strategies is not consistently positive, and it is not possible to ignore the fact that they have also been the subject of sharp criticism because of adverse research findings [46].

Learning to look at the world around us with a physical gaze is not easy, but is important to better understand what is around us. One of the main tasks of teaching is precisely to foster the conceptual transition from a naive interpretation according to personal experience and the common-sense, to an increasingly structured modeling of a disciplinary point of view. Unfortunately, often school teaching does not make students start from vague and unstructured experiences to gradually build a scientific vision and even less to gain a personal cultural appropriation of knowledge. Yet, over multiple years of school, students actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in STEM. The learning experiences provided for students should engage them with fundamental questions about the world and related investigations and answers [47].

Teaching science in informal and non-formal education increases experience excitement, interest, and motivation to learn about phenomena in the natural and physical world ([30], strand 1). It also improves scientific awareness and literacy [48-51], especially when it resorts to hands-on and minds-on activities (see [52] and refs. therein), bolstering motivation to learn science and physics [53-55]. In this regard, the most recent educational research underlines the importance of motivation in learning: it initiates, guides, drives, and maintains goal-oriented behaviors [56-59]. Motivated students tend to engage in class activities and perform better over time. Motivation fosters curiosity toward a subject [60-62] and engages them in pursuing their passions and dreams [63-65].

This paper is the first step in a broader research agenda of the Physics Education Research (PER) group at the University of Cagliari that searches for answers to the following question: can we determine a general framework for the design of active learning programs in informal and non-formal contexts to bring more extensively physics and, in particular, modern and contemporary high energy physics (*e.g.*, general relativity, particle physics, cosmology, and related topics) contents in high school, improving student's motivation, curiosity, and interest in these topics? In this initial study, we illustrate some basic principles that guide the PER group at the University of Cagliari in designing educational strategies and evaluating their effectiveness. We discuss our theoretical framework and present two explicit examples to examine its features and potential role in facilitating the learning of contemporary physics topics, motivating and engaging students in this field.

2. – Theoretical framework and methodology

To develop an appropriate general framework for informal and non-formal learning programs, we need to determine which aspects of programming serve for the programs to operate [9]. Building a robust picture can be interesting for researchers and practitioners who want to integrate such methodologies into their educational programs.

The Educational Division of the Physics Department of the University of Cagliari is developing a theoretical framework based on some basic pedagogical principles to promote the learning of modern and contemporary physics contents (*e.g.*, general relativity, quantum mechanics, particle physics, and cosmology) employing active learning strategies in informal and non-formal environments. Moreover, our intent is also to determine the effectiveness of our methodology.

Following the line of PER described above, all our approaches rely on constructivism-based active learning strategies in informal and non-formal contexts. In particular, we include hands-on and minds-on activities based on the Inquiry Based Science Education (IBSE) pedagogy. In IBSE, knowledge is constructed by an individual through active thinking, reflecting the (active) learning framework we adopted. More specifically, the individual active thinking process builds on the selective attention of the individual, the organization of information, and integration with or replacement of the existing knowledge [66]. Collaboration and social interactions (cooperating for learning, see below) are two interesting features of this pedagogy we also decided to implement in our design. Indeed, an individual needs to be actively engaged both behaviorally and mentally in the learning process for learning to take place. Social interaction fosters this process, also creating shared meaning [66, 67]. Moreover, the IBSE methodology is widely recognized as effective in developing students' science and technology literacy, encouraging them to be involved in inquiry [67-69].

Following this general framework, we focus on two inquiry strategies based on i) problem-solving and ii) interdisciplinarity. We briefly discuss them to illustrate further details of our pedagogical framework and the rationale behind these choices.

Implementing such inquiry-based methodologies is beneficial to train students in learning science through activities that reflect the authenticity of science as practiced by professional scientists and to present contents as practical and manageable within the school context [45]. The use of problem-solving pedagogy was demonstrated to be very effective in reaching this goal [70, 71]. Problem-solving (PS) is the ability of one person to cope with a problem, the latter being a new situation that requires elaborating previous knowledge and experience to achieve the solution [72, 73]. It is a strongly requested skill in STEM courses, the professional and social world, and to manage new situations and contexts [74]. Teaching problem-solving strategies to students was demonstrated to be very effective in improving their performances in physics and their professional and personal skills (see [75-77] and refs therein), as also requested by many science and education curricula [67].

Among the numerous methods to teach PS, Bell *et al.* proposed a four-PS step process [78]: 1) Understand the problem; 2) Make a plan; 3) Carry out the plan; and 4) Look back to your work. While the authors did recommend some reflection at the end to help the solver understand what worked well and what did not, his suggested procedure does not emphasize the necessary monitoring phase to arrive at a successful solution to a given problem. Bransford and Stein developed the "ideal" method of PS, which includes the step "Explore Alternative Approaches" [79]. While this does encourage students to do some monitoring, it does not strongly encourage different ways of doing it throughout the solution process. Heller [80, 81] proposed to implement the solving strategy in cooperative grouping by focusing on cooperation as a feature in the learning process (see [82, 83] for similar attempts). Cooperative learning was successful at high school and college levels in improving students' achievements and teaching approaches [84-86]. Cognitive studies in the field confirm this aspect, showing that sharing different points of view to solve a common problem involves cognitive development and more effective learning [1]. Cooperative learning and PS methodologies find a realization in the so-called Cooperative Problem-Solving (CPS) method. The CPS is a social interaction of multiple entities working together (in a group) to achieve a common goal. It is based on the pedagogical model developed at the School of Physics and Astronomy of the University of Minnesota [80, 81] and on the model of Peer Instruction developed at Harvard [87]. The application of the CPS in physics involves the use of a shared framework for the solution of complex problems with a rich context. We selected this particular framework because it accomplishes the target of stimulating the interaction of a group to achieve a common goal. It can be helpful for students and teachers (novices and experts, respectively) to deal with the categories and the representation of a physics problem [13]. It also helps them give meaning to notions and concepts they learn at school; it stimulates student engagement in the activity, making them live a concrete physical situation, possibly derived from researchers' experiences in research (see [83] and refs therein).

More in detail, our CPS strategy comprehends the implementation of the four-step problem-solving process by Bell *et al.* discussed above in cooperative learning contexts as in [80, 81], followed by a final reflection session to help the solver understand what worked and what did not, as suggested in [78].

Offering an interdisciplinary vision of science to high school students and teachers is becoming a common trend of informal learning (see [88-90] 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 [91].

The engagement of the history of science in science education satisfies these requirements leading to many benefits in the training of prospective vocational scientists and in educating the broader public about the nature of science [92, 93]. Historicizing science in the classroom can improve the pedagogical experience of science teachers and students, evolving the latter into professionals of science [94]. Besides the introduction of elements of the history of science, the role of the philosophy of science can be of interest in education, too, and inquiry methodologies could be central to reach this goal. Since the 1950s, PER studies have shown that students often deeply ingrain intuitive beliefs and conceptions regarding natural processes [95]. These can affect how they see the world, their understanding of new concepts, and how the student inquires [96, 97]. The introduction of the philosophy of science in high school curricula, possibly using active learning strategies, can stem the influence of misconception in the learning of science, fostering conceptual learning, as well as students' attitudes toward the nature of science, argumentation, meta-cognition and a deeper understanding of scientific ideas [98-101].

However, while science education standards documents in many countries also stress the importance of teaching and learning the history and philosophy of science, the approach in question still suffers from ineffective implementation in school science teaching [102]. Fundamental and conceptual questions in physics are sometimes hidden from students since it is not easy to implement them in a standard scholarly learning design [103]. However, introducing these topics in the class, contextualizing them along the lines of the history of science, focusing on the role of debates and controversy in the evolution of science, and proposing science-reflexive meta-discourses could help teachers presenting physics as a unified textbook knowledge [98, 104]. We argue this can also improve students' personal and PS skills, as suggested by previous work in PER [105-110]. For these reasons, we are implementing interdisciplinarity in the design of active learning programs on contemporary high-energy physics topics to promote the learning of physics in high schools in informal and non-formal contexts, and to foster students' motivation, interest, and engagement in this field.

2·1. *Evaluation issues.* – Measuring the efficacy of informal learning strategies is significant to investigate the motivation, interest, and approach/attitude toward physics or STEM [111]. Indeed, if, on the one hand, the positive effects of informal and non-formal learning of physics in the pedagogical and psychological domains are well studied, in the literature, on the other hand, it also emerges the (quasi-total) absence of research work that investigates the effectiveness of informal teaching on cognitive and non-cognitive learning outcomes (with rare exceptions) [9, 112]. Since each activity is specific, it is not easy to individuate some general and common aspects in all of them. Moreover, the lack of a formal environment prevents the possibility of making mid- and long-term studies to investigate the efficacy of such activities over time.

Qualitative (personal or aggregate local feedback) or formal semi-quantitative or quantitative measures can be done to investigate the efficacy of a given educational strategy in some specific domains, such as the cognitive, pedagogical, and affective ones. The cognitive domain encloses the knowledge and the understanding of a specific subject.

The pedagogical domain relies, for example, on the learning of content, the implementation of specific methodologies in school, the measures of the public understanding of science [113], etc. The affective domain encloses motivation, passion, and interest towards a specific subject or matter, as well as emotive expectations and final satisfaction towards the activity itself [48, 49].

As suggested by PER, we study the domains cited above by constructing a self-report questionnaire. According to our research goals, if possible, we used validated questionnaires or some items from validated scales to investigate the domains cited above. If not, we build the measure inspired by research in the same field. The questionnaire collects data about the sample, such as demography or other generic and descriptive information (grade, type of school, age distribution of participants, gender, other); feedback on the organization of the activity; motivation, curiosity, and interest in physics and the proposed activities. We send questionnaires to participants at the end of the activities. We carry out the quantitative and qualitative analysis of collected data according to standard techniques of PER (see, for example, [76, 114-117]).

We introduce formative evaluation methods [118-120] in our methodology to qualitatively measure the learning level of students. They include creative tasks such as writing texts (*e.g.*, posts to publish on social networks, such as Instagram or Facebook), class quizzes, and debates. These activities foster students' interest in physics, invoking their creativity and personal re-elaboration of concepts suitably adapted to the features of the activities proposed [121, 122].

3. – Examples

Here we illustrate two examples of educational strategies designed by the PER Division of the University of Cagliari based on the two main active learning approaches cited above: i) problem-solving activities; and ii) interdisciplinarity.

3˙1. *Problem-solving activities*. – Here we describe the design of a masterclass based on CPS methodology organized by us within the "Dark" and "AriaPerTutti" outreach programs of the National Institute for Nuclear Physics (INFN) [123], and the Aria Project [124], respectively. The activity was carried out at the Physics Department of the University of Cagliari (Italy) on February 10th, 2023, during local celebrations for the International Day of Women in Science [125].

The scientific context of the masterclass was that of the dark matter search in the DarkSide experiment [126]. More specifically, the content of the class focused on the findings of researchers from the Aria Project, an experimental distillation column, the first of its kind, used for the purification of argon, as well as an innovative industrial plant with the purpose of the production of stable isotopes [127]. Argon is a noble gas that will be used as a target material for dark matter detection in the DarkSide experiment [128].

The sample consisted of 8 students from different high schools in Sardinia (m=3, f=5; 1 attending the third grade, 3 from the fourth grade, 4 from the fifth grade; 6 from the scientific, 1 from "humanities", 1 from "technical" high school). The activity lasted six hours. We held it in one day. We obtained informed consent from participants to participate in the study and to publish its results. Their participation in the study was voluntary and anonymous.

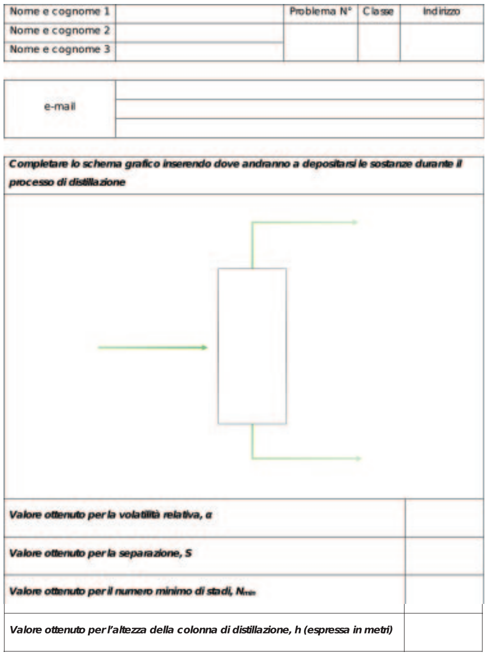
We devoted the first part of the morning session (90 minutes) to theoretical seminars on dark matter and related topics [129]: the astrophysical rationale behind the dark matter hypothesis (rotational curves, bullet cluster, cosmology) and particle dark matter candidates (the Weakly Interacting Massive Particle hypothesis); dark matter detectors and the DarkSide experiment [126]; isotopes, noble gases and the use of argon as a target to detect the dark matter particles in such experiments; the Aria project and its plant's construction details; the functioning of distillation columns; the application of stable isotopes in dark matter searches and nuclear medicine.

Concerning the physics behind the project, we detailed the thermodynamics of the distillation process and the phase changes, such as evaporation and condensation, needed for the column's operation. One of the masterclass' goals was learning the fundamental parameters of sizing a distillation column. Using the Fenske equation [130], students determined the minimal number of theoretical stages of a distillation column for an ideal distillation process. They could also learn in which way the number of stages can vary as a function of the thermodynamics variables of the system (the working pressure of the column and the temperature gradient among the substances present in the mixtures to separate through distillation). See [131-134] for details on the distillation process and [127, 128] for details on the Aria column.

To do so, we designed a specific CPS program for our target. We prepared four different text-enriched problems. They had a similar structure, only differing for the thermodynamics parameter involved in the calculations. In particular, two of them concerned the separation of argon from oxygen in an argon-oxygen mixture. In one case, we set the working pressure of the column at 1 bar and, in the other, at 3 bar. We did the same for the other two problems, where students had to calculate the separation of methanol from water in a methanol-water mixture. In this way, students could learn about the effects on the separation efficiency due to variations in the working pressure, as well as the role of gradient temperature among the substances in the mixture for sizing the column [130], as discussed above. We chose these mixtures, characterized by two different physical states at room temperature (vapor state for argon and oxygen and liquid for methanol and water), as a didactic tool to guide students in understanding two fundamental concepts in the distillation process: the saturation temperatures and pressures (that are different for each substance); and cryogenics, that is the behavior of materials at very low temperatures. This aspect is of relevance for the production of argon in the Aria Project since argon reaches the liquid state at the cryogenic temperature of 87 K at a pressure of 1 bar.

We first divided students into four groups (two people each). The CPS activities started with researchers illustrating the problems and their structure (first step). The activity lasted 30 minutes. After that, the groups cooperated to make a solution plan (second step) and solve problems (third step) under the supervision of researchers, who acted as facilitators. This activity lasted 90 minutes. Supervising students during the CPS activity was necessary due to the complexity of the proposed subject, which goes beyond the arguments and the learning goals of the high-school curriculum. Thus, the researchers discussed and gave the formulae to solve problems during PS step one. Nevertheless, students had to implement the solution plan to properly use those formulae to solve the problems using our methodology for CPS, as discussed in the previous section. Each group presented the problem's solutions using the template in fig. 1.

In the last part of the morning session and before lunch break, each group reflected on its work and results, starting to discuss it with the researchers and the other groups (fourth step). This activity lasted 60 minutes. After lunch, the masterclass ended with a session (120 minutes) where each group summarized their results using a slide presentation. Researchers moderated the group discussion to analyze the relevant differences between the four case studies proposed. Students simulated a research-like experience in



Nome e cognome 1		Problema N°	Classe	Indirizzo
Nome e cognome 2				
Nome e cognome 3				

e-mail	

Completare lo schema grafico inserendo dove andranno a depositarsi le sostanze durante il processo di distillazione

Valore ottenuto per la volatilità relativa, α	
Valore ottenuto per la separazione, S	
Valore ottenuto per il numero minimo di stadi, N_{min}	
Valore ottenuto per l'altezza della colonna di distillazione, h (espressa in metri)	

Fig. 1. – The panel shows the template to report students' results on their CPS activity within the Aria Project masterclass.

telling their results to their peers. Every group got 10 minutes for the speech. Researchers guided them in preparing the slides for this activity (30 minutes).

We used students' final presentations and group results in problem-solving as formative evaluation instruments to qualitatively measure the learning of concepts and the achievement of requested learning goals. Each group solved the problem of finding the number of stages and the height of their distillation column, satisfying the prefixed learning goals.

We collected students' feedback about the PS activity during the final session. Concerning the structure of the problem, most of the students appreciated it. They did not report any issues with physical or mathematical difficulties in solving it. However, one of them affirmed they encountered some difficulties with mathematics, especially in manipulating exponentials and logarithms as requested by the formulae in the computation of the number of stages of the column [130].

Concerning students' feedback on the final discussion session, they affirmed that preparing the presentation stimulated their scientific creativity, fostering their interest in topics presented during the masterclass. They also appreciated the group discussion and rated it helpful in improving their learning of content.

Concerning their overall experience in the masterclass, they appreciated the methodology, especially for the cooperation, reporting that the latter involved them in solving problems and promoted their socialization. Indeed, they affirmed that the Covid-19 restrictions due to the pandemic prevented from the development of new social relationships in the last two years, and they suffered from the lack of socializing moments even at school. They affirmed that the masterclass improved the socialization process among peers, motivating their active participation during the activities and fostering their learning of content. These findings go in the direction of previous results in PER about the positive influence of socializing on learning [66, 67, 135].

They affirmed that text-enriched problems made them live a real-like research experience (see [83] and references therein for similar results). They appreciated it. Someone also referred they had a strong interest in pursuing STEM careers, and the masterclass motivated them in this direction.

In this case, we did not make any quantitative study implementing a questionnaire because of the small number of participants. This aspect is a limitation of the study, and we left the research for future investigations, where we will implement our CPS methodology in a more specific research program within the "Dark" and "AriaPerTutti" activities.

3·2. *Interdisciplinary approaches.* – The "Gravitas" project is an interdisciplinary outreach and educational program devoted to high school students (17–19 years old) concerning contemporary physics and the philosophy of science [136]. Coordinated by the Cagliari Division of INFN, "Gravitas" started on December 2021 with an unconventional online format: two researchers coming from different fields of research (physics, philosophy of science, history of science, scientific communication) met a moderator and informally talked about gravity and related phenomena. The public could chat and indirectly interact with them during the YouTube live streaming using Mentimeter. The project involved about 250 students from 16 high schools in Sardinia, Italy. Among the active learning activities designed for the project, students created posts thought for social media platforms concerning topics of the seminars they attended during the project.

We organized a series of 16 seminars (formative phase) called "Nuovi Dialoghi sui Massimi Sistemi" ("New Dialogues Concerning the World Systems") dealing with different topics concerning modern and contemporary high energy physics (*e.g.*, general relativity, quantum mechanics, particle physics, black holes, and gravitational waves, dark matter and dark energy, quantum gravity), history of science, philosophy, and science communication. More than 30 researchers from European Institutions participated as speakers. Activities were online (due to the pandemic) from December '21 to April '22.

Inspired by previous work in this field [101, 103, 104, 137-139] and following the prescriptions of our methodology, we decided to monitor the following dimensions: students' motivation towards physics and philosophy on specific items dealt with by the project; how the project influenced students' perception on physics, philosophy, and science communication; students' interest in these three fields. We also investigated students' feelings about a possible implementation of the Gravitas methodology in schools. Students could answer using a 6-point Likert scale, from 1 (completely disagree) to 6 (completely agree). We obtained informed consent from participants to participate in the study and to publish its results. Participating in the study was voluntary and anonymous. Figures 2–7 shows items investigated by the questionnaire.

Concerning students attending the online program, 236 students (m=128, f=108) from 16 high schools in Sardinia (years: 17, n=63; 18, n=130; 19, n=43). Only 127 students (m=72, f=55; 111 from scientific, 9 from "humanities", 7 from artistic high schools) fully completed project learning requirements creating four posts on the four different topics they appreciated the most during the formative phase (to be posted on social networks such as Gravitas' Facebook and Instagram profiles). Participants could

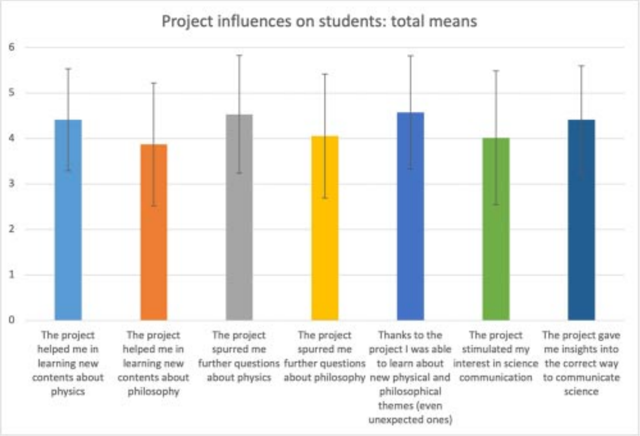


Fig. 2. – The panel shows the means related to the influence the project had on students about physics, philosophy, and science communication. Error bars are the standard deviation.

also work in a group in a cooperative learning framework. We used this strategy as a formative evaluation to gather qualitative feedback on students' understanding and learning of contents.

Concerning the research questionnaire, we collected 70 answers (m=42, f=28) from April (end of the project) to June 2022 and qualitatively analyzed them by calculating the mean and related standard deviation. To determine whether there were any statistically significant differences between means on items based on gender, we carried out an analysis of variance (ANOVA, not shown here). The reliability of the instruments, measured by Cronbach's alpha coefficient, was higher than .80. See also [136] for further details.

Most of the students were satisfied with the learning design and methods used during the project (fig. 2). On average, they affirmed the project helped them in learning new concepts related to contemporary physics (dark matter, general relativity, cosmology, particle physics, quantum gravity) and the philosophy of science. Concerning the latter, they particularly appreciated the philosophical argumentations and debates around a given scientific topic. We used these data to monitor how much our activity influences students' motivation and in which specific item the effect is higher. This tool helped us find some problems related to our project design. For example, students mentioned that they could communicate with researchers through Mentimeter or YouTube live chat but preferred to talk and chat directly with them to satisfy their learning curiosities.

Qualitative analysis shows an overall positive influence of the project on students' motivation towards physics, philosophy, and science communication fig. 3. Results showed that scores were slightly higher in physics than in other disciplines (even if the differences are not statistically significant). In some sense, we expected this result since Gravitas' activities mainly focused on physics, and students participated in the project because of their interest in this subject. Moreover, we noted that regardless of their research field, speakers used philosophical arguments and scientific communication tools to foster students' motivation and interest in these topics rather than going deeply into the conceptual aspects of the two disciplines. Students affirmed feeling motivated to participate in the project.

They appreciated experiencing the "Gravitas" format and thought it as exportable

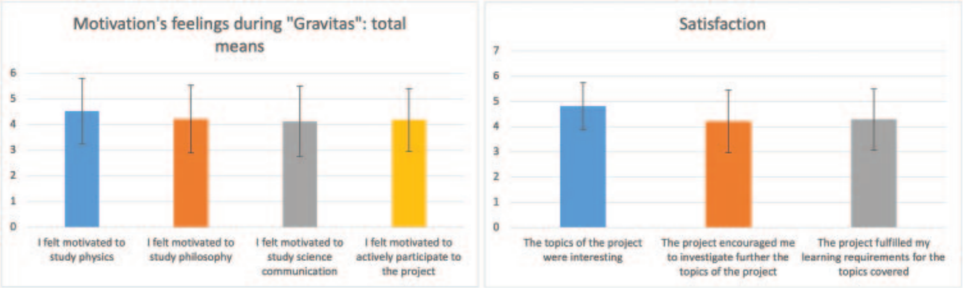


Fig. 3. – Students' motivation (on the left) and satisfaction (on the right) in specific topics while they were attending the project. Error bars are the standard deviation. The ranking scale goes from 1 (completely disagree) to 6 (completely agree).

even to the classroom, especially for the interdisciplinary approach that mixes physics and philosophy, see fig. 4. Most of the students rated the latter with high votes and appreciated the format, affirming that it would be a tool to involve them more in learning contents of many high school disciplines. They also affirmed that using Gravitas' seminars on YouTube at school can promote in-class discussion on topics related to contemporary physics and the philosophy of science. This finding confirms previous research on learning physics in online environments (see [29] and refs therein).

Students affirmed their interest in physics, philosophy, and science communication raised during the project (fig. 5). This result goes in the direction of other studies in the field of informal learning, suggesting the importance of these activities to foster students' interest, passion, and motivation in science [7, 31, 48, 60-65, 142].

Interdisciplinarity is one of the key points of Gravitas. The continuous interplay among physics, philosophy, and history of science glued by science communication contents and tools, allowed students to enlarge their horizon from a specific field to a general vision of science (see fig. 4). Most of the students got in touch with research and phe-

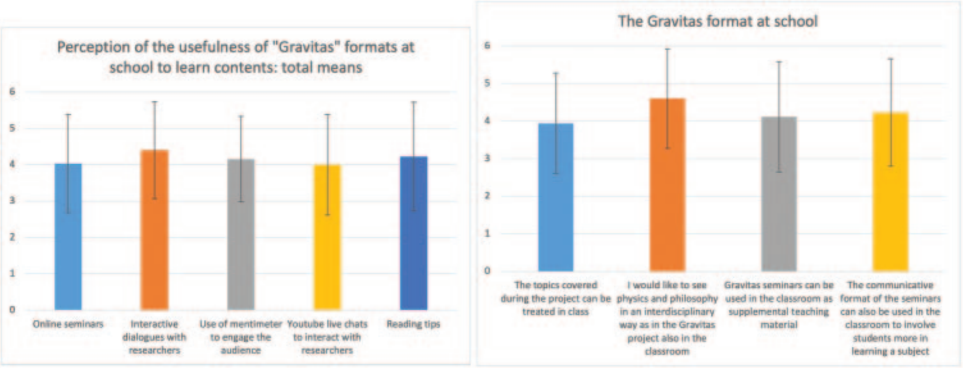


Fig. 4. – The panel shows a) on the left, the means related to students' perception of the usefulness of the "Gravitas" format at school to learn contents; on the right (b), students' feedback about the implementation of "Gravitas" methodology in class. Contents, interdisciplinarity, and the influence of the project on students' perception of the world of science. Error bars are the standard deviation.

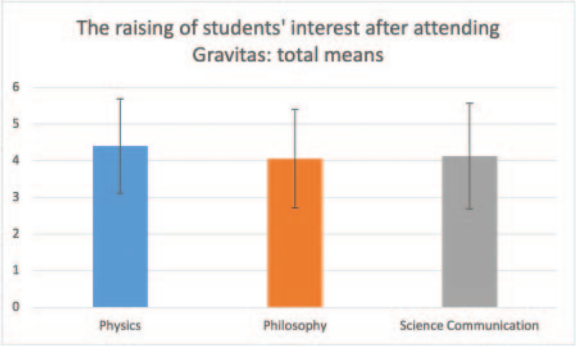


Fig. 5. – The panel shows the means related to students' motivation in studying physics, philosophy, science communication, and in participating in the project during "Gravitas". Error bars are the standard deviation.

nomena currently studied by researchers. They also affirmed that the dialogues helped them in understanding the scientific method, introducing them to the world of science (fig. 6).

Fostering their creativity by writing posts positively influenced them in many domains (fig. 7). Indeed, this activity helped them increase their passion for physics. When asked to leave some free comments on the project (by using an open box in the questionnaire), students underlined the importance of writing a post to re-elaborate what they learned during the project fixing new concepts in their minds. Indeed, this activity motivated them to attend online seminars [121].

The work has some limitations: the sample is small, so we cannot use the positive outcomes we registered in the first edition as a model to test our methodology in interdisciplinary approaches. For this reason, we would like to extend the audience to all of Italy in the next years. However, this is not a problem in itself, due to the intrinsic nature of the activity, mainly devoted to outreach and informal learning of physics. A more

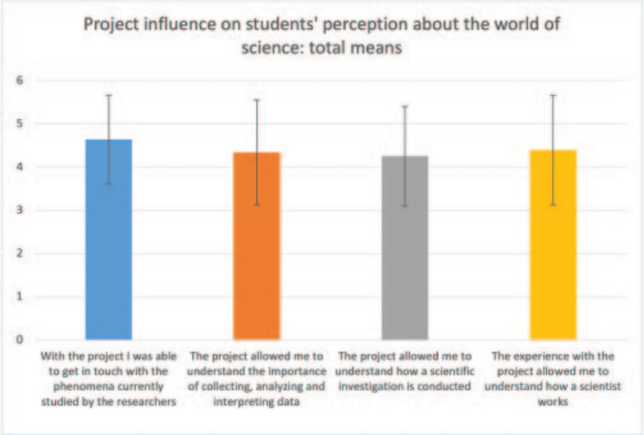


Fig. 6. – The panel shows the means related to the influence of the project on students' perception of the world of science. Error bars are the standard deviation.

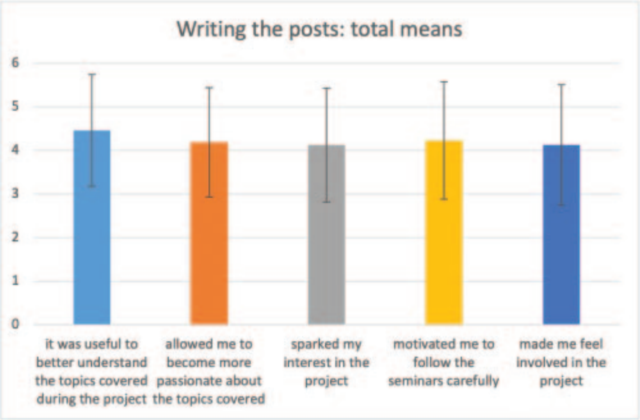


Fig. 7. – On the left (a), the panel shows means related to students' feelings on writing the posts. Error bars are the standard deviation.

robust quantitative analysis is desirable for future studies to gather further information to measure the efficacy of our methodology in these informal learning contexts [140].

4. – Conclusions

This paper is the first step in a broader research agenda of the PER group at the University of Cagliari that searches for answers to the following question: can we determine a general framework for the design of active learning programs in informal and non-formal contexts to bring more extensively physics and, in particular, modern and contemporary high energy physics (*e.g.*, general relativity, particle physics, cosmology, and related topics) contents in high schools, improving students' motivation, curiosity, and interest in these fields?

In this initial study, we illustrated some basic principles that guide the PER group at the University of Cagliari in designing educational strategies to reach our research goals. We discussed our theoretical framework and methodology. We presented two explicit examples where we examined the features and the potential role of our approach in facilitating high school students learning of modern and contemporary physics, motivating and engaging them in these fields.

The results of our studies are encouraging. High school curricula do not include contemporary physics topics because of their conceptual and mathematical intrinsic difficulties. Implementing active learning strategies (such as the CPS) in interdisciplinary contexts seems promising in reaching our research goals. In particular, informal and non-formal contexts allowed us to make educational experimentations to promote the learning of physics in high schools. This result goes in the direction of previous studies in the field of informal learning, suggesting the importance of these activities in fostering students' interest, passion, and motivation in science [7, 31, 48, 52, 53, 60-65, 142].

However, future studies are needed to develop a general framework to measure the efficacy of our methodologies in the domains we are investigating, namely motivation, engagement, interest, and learning of contents. The implementation of our methodology with large-size samples and the development of suitable research questionnaires could be a valid attempt in this direction, as suggested by already existing studies in this field [18,41,66,135].

Another issue we left for future investigations is to understand how our design and, more in general, active learning strategies in informal and non-formal contexts positively influence students' motivation and engagement in modern and contemporary physics. Indeed, our interests are in finding the cognitive and learning parameters involved during this process and how our methodological framework influences or activates them. We propose that specific research goal-orientated interviews could help achieve this goal [9, 33,60]. A similar study could be done to investigate the influence of our methodology in promoting high school students' inquiry and understanding of the nature of science [101, 103].

* * *

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