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Interdisciplinary approaches to foster the learning of contemporary physics in high schools: A methodological proposal

M. Tuveri(1)(2)(*)

(1) *Dipartimento di Fisica, Università di Cagliari - Cagliari, Italy*
(2) *INFN, Sezione di Cagliari - Cagliari, Italy*

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Summary. — Informal contexts represent the ideal stage for didactical and teaching experimentations, facilitating interdisciplinary approaches in education and fostering students' motivation, creativity, curiosity and interest in physics. We discuss the features of such approaches and their role in bringing contemporary physics topics to high school and how educational practices developed in an informal context can also be used to integrate formal educational programs. Finally, we also focus on how to qualitatively and quantitatively measure the efficacy of these educational strategies by using suitable research questionnaires.

1. – Introduction

During our lives, we spend most of our learning time in informal contexts, out-of-school time, and outdoor activities, such as families, science outreach labs, visits to museums, summer camps, social networks, TV shows and newspapers (see [1] and references therein). These are just examples of informal education environments, and their role in education is increasingly recognized at institutional, scholarly and academic levels [2]. Informal learning is structurally non-didactic, built on the learner's initiative, interest, or choice [3, 4].

Over the decades, studies in Physics Education Research (PER) have shown that learning physics in informal contexts increases experience excitement, interest and motivation to learn about phenomena in the natural and physical world, also improving scientific awareness and literacy [5, 6], especially when it resorts to inquiry-based, hands-on and minds-on activities [7], bolstering motivation to learn science and physics [8]. Informal contexts allow instructors to carry out teaching experiments so much that in these contexts, interdisciplinary becomes an educational tool. Interdisciplinary, in its simplest form, constitutes an appreciation of different discipline fields (*e.g.*, physics, PER, science communication, arts) and the value of communicating across disciplinary boundaries to find ways to work together. As emphasized in [9], playing and learning content and methods from different disciplines bring educators and students to develop

(*) Corresponding author. E-mail: `matteo.tuveri@ca.infn.it`

new scientific reasoning and toolkits. Moreover, research results show that arts, narrative and drama help students reflect on scientific concepts and science evolution from epistemological and historical perspectives [10]. It also promotes peer interaction at school and interaction among school, family and society [11]. Learning experiences and skills acquired through interdisciplinary apply physics fundamentals to real-world solutions, connecting the world of research and society [1].

This paper illustrates our methodology to design suitable interdisciplinary programs aimed at high-school students (grades 10–12). Topics rely on contemporary high-energy physics and, in particular, on cosmology. The rationale behind this proposal is to explore methodologies widely used in informal learning contexts that mix physics with arts, history and philosophy of science in bringing more extensively contemporary high-energy physics into formal high school curricula. The aim is to improve student's engagement, motivation, curiosity, and interest in these topics. This work can furnish a theoretical and methodological guide for teachers and instructors on integrating the good practices of informal learning and interdisciplinary approaches in their formal curricula.

2. – Theoretical framework and methodology

PER shows that enhancing students' engagement in physics is possible by using interdisciplinary approaches [10]. In our methodology, we advocate interdisciplinary research by mixing contemporary physics, the history of physics, the philosophy of science and the arts. Indeed, the engagement of the history of science in science education leads to many benefits in orienting students to STEAM (Science, Technology, Arts and Mathematics) careers and in educating the broader public about the nature of science [12, 13]. 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 reaching this goal [1]. However, while science education stresses the importance of teaching and learning the history and philosophy of science, the approach still needs to be more effective in school science teaching [14]. 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 [15, 16].

Measuring the efficacy of informal learning strategies is significant in investigating many domains, such as the one related to motivation, interest and approach/attitude toward physics or STEM [17]. In general, 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 domain, according to the design of the activity. In terms of feedback, one can collect data concerning students' engagement (motivation, interest, creativity). However, sometimes one can also investigate the learning of content and the possibility of implementing the interdisciplinary methodologies at school [1], as well as emotive expectations and final satisfaction towards the activity itself [5]. Following a PER perspective, we conduct our investigations by constructing a self-report questionnaire. According to our specific research goals, 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 —see [1] for more details. We qualitatively measure students' learning levels using formative evaluation methods [18], including creative tasks such as writing texts (*e.g.*, posts to publish on social networks, such as Instagram or Facebook). 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 [19].

3. – Example

Cosmology offers the ideal stage to implement such interdisciplinary approaches. In the broader sense, cosmology relates to the world views held by students, providing conceptual, theoretical and experimental means for bridging the gap between science teaching and humanistic subjects [20]. For example, explaining the origin of the term "Big Bang" represents such an attempt. The word itself is a metaphor, a linguistic and artistic tool used to imagine and describe the unknown: the initial state of our universe according to the Standard Model of Cosmology [21]. Used for the first time by Fred Hoyle in 1949 during a radio show, as noted by Helge Kragh [22], the term has not been often used by physicists in their papers also because of the intrinsic limits of the analogy(1). Physicists and instructors still refer to it when talking about the initial state of the universe, thus leading students to wrong interpretations of phenomena and related misconceptions on this topic. Talking about cosmological topics at school not only allows instructors to introduce students to phenomena in our universe and their conceptions about them, but also offers the possibility to debate about what is science and what is not, what can be measurable and what is not, thus re-enforcing their critical thinking [20].

For completeness, we make an example of a qualitative measure of students' cosmology learning within the "Gravitas Project". It is an interdisciplinary informal learning project designed by the PER group at the University of Cagliari (Unica) and the Cagliari division of the National Institute of Nuclear Physics [1]. Topics covered contemporary high-energy physics and related historical and philosophical issues. As a mandatory activity, students (divided into groups of three people each) should write four texts for social networks concerning what they learned during the sixteen interdisciplinary dialogues between scientists and philosophers they attended during the project (the videos are on the INFN Cagliari YouTube Channel). Here, we show one text (English translation by us) by a group of students attending the 10th grade (third class in Italy) of a scientific lyceum. Its title is "The dark side of matter":

Dark matter and dark energy play a fundamental role in our understanding of the universe, but their nature is still unknown. We only know their general features. To better understand these two elements, we rely on the theory of general relativity, with a cosmological constant to which, however, we cannot assign a precise value. To better understand dark energy, we should improve our observations through innovative technologies that allow us to obtain more specific measurements of the constant. During this century, we will study the dark entities in depth because their understanding is what we lack to have complete knowledge of the cosmos on a large scale.

They wrote about two open problems of cosmology, namely dark matter and dark energy, along the lines of the theory of general relativity. They focused on the Hubble tension problem, *i.e.*, the deviation between the Hubble constant estimations measured by the local distance ladder and the cosmic microwave background measurement [23]. The text resumed the topic of the dialogue with accuracy, highlighting the challenges cosmologists should face in the near future and related implications for our understanding

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(1) The existence of a "bang" implies the need for a place in space and a proper time where an explosion has occurred, whereas the "Big Bang" corresponds to the birth of the concepts of space and time themselves. Moreover, the bomb analogy in vogue after the Second World War was not very much appreciated by the scientific community [22].

of the universe. This text is an excellent example of communicating science in a social network: it is short, well-written, and able to inform people of current research topics and challenges in cosmology, stimulating curiosity in the reader. They also chose some hashtags to link the text to trends and topics in social networks, adequately representing their contents: physics, astrophysics, dark matter and the universe.

4. – Conclusions

In this paper, we illustrated some basic principles that guide the PER group at Unica in designing educational interdisciplinary strategies to bring contemporary high-energy physics topics to high school. We discussed our theoretical framework and methodology, making a specific example in the case of cosmology. We illustrated the importance of offering an interdisciplinary perspective to students to introduce them to contemporary physics. As noted in [24], this approach can also help students feel motivated to pursue a STEM career, even preventing students from school abandon. Future studies are needed to develop a general framework to quantitatively measure the efficacy of our methodologies, such as large-size samples and the development of suitable research questionnaires.

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