DISCIPLINES AND INTERDISCIPLINARITY IN STEM EDUCATION TO FOSTER SCIENTIFIC AUTHENTICITY AND DEVELOP EPISTEMIC SKILLS

In this contribution, we focus on the tension between the traditional organization of school knowledge in disciplines and the STEM interdisciplinary skills required by society and labour market. We discuss the pros and cons of a disciplinary approach to knowledge so as to argue that disciplines can still play a relevant educational role, provided that they are explicitly exploited as forms of knowledge organization able to develop epistemic skills, whilst knowledge is build. We then explore STEM interdisciplinarity as a fundamental aspect to make students experience authentic science. On the basis of these reflections, the tension mentioned above is turned into the research problem to find an equilibrium, in teaching, between exploiting the educational potential of disciplines to develop epistemic skills and fostering scientific authenticity. This research problem is illustrated by examining two cases that refer to different types of interdisciplinarity: the first type emerges from disciplinary curricula and refers to the need to cross curricular disciplines to address a conceptual and epistemological problem; the second case emerges from the society and labour market and refers to the need to address, in teaching, a real STEM topic. More specifically, the first case concerns the educational problem to grasp the nature and the meaning of the quantum breakthrough induced by the problem of the black-body radiation that puzzled the scientists at the end of XIX Century. The second issue concerns the educational problem to address, at the secondary school level, artificial intelligence. On the basis of the examples, we will discuss how and why interdisciplinarity should not be confused either with a–disciplinarity or multidiscipliarity and why epistemic skills can be more effectively formed in a comparative and interdisciplinary perspective: that is, if different disciplines are compared and if both specific and transversal skills are pointed out.

Keywords: Interdisciplinarity; STEM education; Authenticity

DISCIPLINES AND SOCIETAL CHALLENGES: LOOKING FOR EQUILIBRIUM

In the overwhelming majority of countries and educational grades, from primary school to university, curricula are organized in disciplines, like mathematics, sciences, physics. Moreover, the background of teachers and curriculum developers' are, in most cases, disciplinary.

However, recommendations for an educational switch from knowledge to skills and/or for teaching in a STEM perspective have been coming from outside the schools (policy makers, entrepreneurial world, labour market). This pressure is due to the belief that students have to be prepared to cope with those contemporary societal challenges (e.g. climate change, artificial intelligence, nanotechnologies) that are significantly impacting their perception of the future and their role in the present and future societies. These challenges require a deep interdisciplinary preparation, as well as a deep redefinition of traditional disciplinary teaching. Another relevant issue in designing long-term students curricula is the unpredictably ever-changing labour market: new professions are continuously appearing and traditional professions are disappearing. What is the role of traditional disciplines in this big picture? What space should we reserve for their teaching? Are they becoming unnecessary or do they still play a relevant role?

In this contribution, we will focus on the tension between the traditional organization of school knowledge in disciplines and the interdisciplinary skills required by society and labour market. We will try to argue why neither the traditional disciplinary approach to knowledge nor an a-disciplinary approach, based on transversal skills, is productive to give back knowledge and skills to address authentic problems concerning, on one hand, scientific thinking and, on the other, the relation between science and society. We propose two examples of authentic problems that require interdisciplinary approaches to knowledge organization to solve the current tension. We will use S-T-E-M disciplines to consider separately Sciences, Technology, Engineering and Mathematics as traditional disciplines, while we will use STEM to refer to the integration of the disciplines to deal with problems and applications.

INTERDISCIPLINARITY AND AUTHENTICITY IN S-T-E-M AND STEM EDUCATION

The meaning of interdisciplinarity cannot ignore the meaning of "discipline". The term "discipline" contains the Latin root "*discere*", whose meaning is to learn. Disciplines can be seen as a re-organizations of the knowledge with the scope of teaching it. In particular, disciplines ground their roots into the didactical necessity of re-organizing knowledge in such a way that student, whilst building their knowledge, can also develop epistemic skills, like problem solving, modelling, representing, arguing, testing, communicating, sharing, producing. Disciplines should help student to make gradually sense of different categories of problems, approaches, tools and criteria to evaluate the correctness and efficiency of a procedure, a reasoning, an argument. This implied the necessity to transform knowledge into rigorous and recognizable definitions and its practices into repeatable methods. Nowadays, when disciplinary teaching is turned into a mere repository of information and fails in developing thinking epistemic skills, it betrays the very scope and sense of disciplines. In this paper we assume that disciplines can still play a relevant educational role, provided that they are explicitly exploited as *forms of knowledge organization*. We will moreover argue that epistemic skills can be more effectively formed in a comparative and interdisciplinary perspective: that is, if different disciplines are compared and if both specific and transversal skills are pointed out.

Relying on Thompson's definition (Frodeman, Thompson and Mitcham, 1990, p. 16), we speak of interdisciplinarity when disciplines mutually integrate, interact and blend, while we consider multi-disciplinary an approach in which disciplines are juxtaposed, sequential and coordinating. We consider two kinds of interdisciplinarity: the first emerges from the societal and labour market challenges and the applications of STEM knowledge in working contexts (research teams, industries, socio-economic development agencies, policy makers) while the second is an integration among curricular S-T-E-M disciplines. Kapon, Laherto and Levrini (2018) linked the development and application of knowledge and the teaching-learning of disciplines in educational context by means of the concept of *disciplinary authenticity, i.e.* "learning experiences must be deeply rooted in and reflect the nature of both contemporary scientific endeavor as well as throughout the history of science"; it can be pursues "by emphasizing the practices of doing science and generating scientific knowledge, while other, more historical-philosophical–oriented settings may emphasize critical reflection on the epistemological and historical processes of the development of scientific knowledge." (p. 1078).

If we look at disciplines from outside the educational system (schools and universities), we can notice that the definition by the National Academies Committee on Facilitating Interdisciplinary Research (Kates, 2005) stresses a clear link between authentic research practices and interdisciplinarity: "Interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice" (p. 2). Interdisciplinary between science, mathematics and technology deeply characterizes the historical evolution of S-T-E-M knowledge (Tzanakis, 2016). But nowadays interdisciplinarity is a key-word for current research and for the flourishing of new STEM fields, like data science and computation, artificial intelligence or climate science.

In light of the previous remarks, the tension between disciplinary teaching and the interdisciplinary skills required by society and labour market can be turned into the problem to find an equilibrium between exploiting science authenticity and the educational potential of disciplines to develop epistemic skills.

We wondered: How can disciplinary knowledge and disciplinary epistemic skills be exploited or developed in teaching, whilst coping with authentic (interdisciplinary) STEM issues? If so, what authentic (interdisciplinary) STEM issues can be used to guide students to exploit or develop their disciplinary knowledge and disciplinary epistemic skills? What teaching approaches can be applied?

We will discuss the above questions by presenting two examples of authentic (interdisciplinary) STEM issues. The first issue concerns the need to cross the boundaries between physics and mathematics to grasp the nature and the meaning of the quantum breakthrough induced by the problem of the black-body radiation that puzzled the scientists at the end of XIX Century. The second issue concerns the teaching, at the secondary school level, STEM topics like climate change and artificial intelligence.

EXAMINING AND PROBLEMATIZING: TWO DIFFERENT KINDS OF INTERDISCIPLINARITY IN S-T-E-M AND STEM EDUCATION

Authentic interdisciplinarity in disciplinary contexts

The problem of blackbody radiation played a crucial historical role, inducing the quantum revolution. Nevertheless, in teaching it is treated, usually, as a mere information, because of its inner complexity. Partly such a complexity is due to its authentic interdisciplinary nature. Indeed, starting from an interdisciplinary, both theoretical and applicative, problem - the study of blackbody radiation - Planck came to undermine basic principles of classical physics as result of complex reasoning in which mathematics played a structural, not only an instrumental role, and purely mathematical theorems and arguments were used together with empirical and model-based considerations (Branchetti, Cattabriga, Levrini, submitted). The atypical form of argumentation made the analysis of Planck's reasoning one of the most debated topics in the historiography of scientific revolutions. In the contribution, we present how we reconstructed the historical case, by analysing the original papers from an interdisciplinary educational perspective. The analysis made emerge a very interesting interplay between mathematics and physics, epistemologically relevant issues and the inadequacy of teaching materials in communicating the nature and the key points that lead Planck's to his famous hypothesis. On the basis of this analysis, we will use interdisciplinary as a key to compare original memories and textbooks so as to analyse how intrinsically interdisciplinary knowledge was transformed into school disciplinary knowledge. The comparison will show examples of how the transformation are lethal both from an epistemological point of view- "the problem is not cutting in its joints" – and an educational point of view: the transformations compromise seriously, sometimes irreparably, the students' possibility of understanding the structural role of mathematics in physics and the argument that led Planck to open the gate toward a new world. Then we show how it is possible to reconstruct the original papers with the aim to flesh out the interdisciplinary argumentative structure, by stressing the role and the epistemic features of both mathematics and physics. From iterative process of implementation with university students we will discuss how this interdisciplinary approach allowed the students, at the same time, to grasp the disciplinary breakthrough and to reflect on what type of knowledge and epistemic practices (ways of reasoning, representing, modelling, arguing, communicating) characterize a mathematical and a physical approach.

STEM new disciplines and the role of traditional disciplines

The second example concerns the problem of how to address an interdisciplinary issue like Artificial Intelligence (AI) with secondary school students. We designed and implemented a module within the I SEE project (www.iseeproject.eu). The module was produced by a team of researchers in mathematics, physics and computer science education, together with high school teachers and experts in engineering, applied physics, epistemology of science and complex systems. In the beginning, the students were presented some AI applications in many fields, and attended two seminars, about: i. the relationship between AI and complexity science; ii. the history of AI. In the second phase, they were showed different approaches to AI (imperative, logical/declarative, machine learning) applied to the Tic-Tac-Toe game. The "Tic-Tac-Toe activity" is an example of activity aimed at making the role and the peculiarity of traditional disciplines emerge in the context of a new STEM discipline. The activity focuses on conceptual and epistemological knowledge already introduced in the overview lecture, where three possible approaches were presented to teach a machine to reason and to solve a problem: the imperative approach (implemented in many of the most traditional programming languages for example, in PHYTON); the logical-declarative approach (implemented, for example, in PROLOG language); the machine learning approach, based on examples (implemented, for example, in MATLAB). The three approaches mirror the approach to problems typical of Computer science, Mathematics and Physics. It foresees an introduction to the specific approach, stressing the form of reasoning that is assumed and, in particular, stressing: what an algorithm is; what it means to take a decision within an approach; what it means that this approach is symbolic and top-down or sub-symbolic and bottom-up. Starting from a concrete problem, we showed the integration of S-T-E-M discipline into a STEM new field of research and application, but we also used the traditional S-T-E-M disciplines epistemologies to shape and clarify the differences between the approaches, and we contributed indirectly to a better understanding of the traditional disciplines themselves.

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