THE SOUND OF SCIENCE(S): A SOUND-BASED PROJECT FOR INCLUSIVE STEAM EDUCATION AND SCIENCE COMMUNICATION

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Abstract

In the last few years, the development of effective strategies for the improvement of learning performances in scientific disciplines is catalysing the interest of researchers, policy makers, teachers, and educators. Educational research is trying to gain knowledge on what actually works in the classroom. The fast spread of evidence-based education relates to the need of providing functional data that can be used for taking informed decisions. Such approach is leading to introducing novel teaching strategies, supported by scientifically based research and connecting different disciplines within a unifying framework.

The Sound of Science(s) is an interdisciplinary research project aimed at developing innovation in educational STEAM research by exploring equitable, creative and inclusive learning modes. We are working on the implementation of a communication system capable of transferring scientific knowledge by using the forms of musical language (and vice versa, approaching music by starting from science), building this correspondence on the common ground of symmetries and proportions. A preliminary study focusing on the sonification of crystal structure and composition gave indications about the effectiveness of this innovative approach. Our project aims at extending the range of application of sonifications to biology and additional fields of science.

The sonification strategies adopted can be classified into "static" and "dynamic". In the first case, aural models are obtained by seeking a science-based and reproducible “musical counterpart” of the objects modelled (e.g., crystals, cells, structures of living organisms, etc.). The models produced by this approach are then used in teaching through active fruition, and in the professional development of the educators. In the case of dynamic sonification strategies, the sound models are used interactively, through the implementation of a dedicated VR software, and through performances of guided improvisation (conduction) in which the audience “plays" a natural phenomenon (e.g., state transitions, formation of crystalline defects, plant growth and development etc.) according to a predefined code of sonification.

Beside presenting examples and excerpts from our previous sonification activities, we will discuss the opportunity of creating a European network of researchers and educators sharing an interest in bridging science and music for educational purposes. The project is open to the creative and experimental contribution of fellow researchers and educators. If interested, please do not hesitate to contact us (giacomo.eramo@uniba.it).

Keywords: STEAM, sonification, mineralogy, biology, music, education.

1 INTRODUCTION

Over the last years the European Union has had to deal with several problems which have challenged its common values and principles: marketization, migration waves, climate changes, economic crises, the Covid-19 pandemic and last but not least, the recent war in Ukraine. All these problems exerted a great pressure on the European societies called to review their traditional way of conceiving life, work, health. In a so delicate historical phase, the role of science as a linked and jointly liable knowledge connecting environment, society, economy, art and institutions in order to foster active citizenship, inclusion and eradication of poverty, clearly arises.

In this vein, several studies subsidized by the European Community, since 2018, have showed that, while there is a strong need of high-level competences, different problems occur in the STEAM education field across the EU national school systems. More specifically, STEAM education is perceived as not very interesting; there is a considerable gender gap in scientific academic careers; the inclusion of disadvantaged people is still scant.

For these reasons, the improvement of the value of the scientific thinking is crucial. Far from a dogmatic tradition, the scientific thinking is a habitus: a specific view of the world characterized by continuous research, analysis, resourcefulness, humility and open mind to share and compare personal ideas. It is a posture, a transversal approach to reality, that connects, through creativity and critical thinking, stable and accepted rules and principles allowing all knowledge fields to contribute solving in innovative way life problems. Integration is the key component in STEAM education.

1.1 Educational issues after the Covid-19 pandemic

Due to the Covid-19 pandemic, over the last two years, the worrying problem of the educational poverty increased. Save the Children describes it as a process of limitation of children's right to education and deprivation of their opportunities to learn and develop the skills they will need to succeed in a rapidly changing society.

At the same time, the pandemic has stressed the importance of the scientific knowledge in the daily life, as well as the fundamental relationship between science and society in order to defeat diseases and promote health. This topic is aligned with the educational challenge of the promotion of a scientific citizenship which means, in policy, economic, cultural and social terms, the chance to access and appreciate scientific knowledge and progresses. Scientific citizenship represents, in fact, an informed practice of citizenship rights. Therefore, the big themes of public communication of science by school and mass-media are of extreme importance. To this aim, it is also important the active involvement of students in the scientific and technological knowledge communication and dissemination. School represents, thus, a real smithy of scientific citizenship. A recent survey realized in Italy by Ipsos (Save the Children, 2021) on a representative sample of 1000 boys and girls, aged between 14 and 18, showed how these participants demonstrate a slightly positive conception of science, perceived as objective, engaging, oriented to the common good, even though difficult.

However, data show also some resistances towards the scientific sector, especially by students in the South of Italy and by girls. The reasons behind this disaffection that diverts students from scientific degree paths at university are related to a low self-efficacy and to the belief of not having the right qualities to succeed in this field. Comparing these data with the 2018 OCSE-PISA results in the science domain it is clear how Italy is below the OCSE average and at the bottom of the European countries rank with a benchmark of 468 compared to the average of 489. More specifically, the percentage of students aged 15 with an insufficient level of achievement in the scientific domain is of 37.5% in the South compared to the 16.5% average in the North of the country.

There are several reasons for this situation. However, if we focus on teaching or on instructional strategies, it becomes crucial to invest in scientific and technological laboratories at school, as well as in innovative teaching practices. The article 27 of the Universal Declaration of Human Rights (1948) states that "we all have the right to get involved in our community's arts, music, literature and sciences, and the benefits they bring". To preserve this right, transforming educational systems is essential, in order to give students the chance to fight "junk-science" and develop a scientific approach to life. The role of secondary schools, in this framework, is relevant because it can be the place where students, through project-based learning activities and inquiry-based learning processes, develop a creative, scientific, interdisciplinary approach to the learning, that means becoming a lifelong learner.

What is required is a new educational approach in the instructional design that bridges between humanities, life sciences, physical and engineering sciences and mix arts with knowledge and practice. Teaching young students to develop and use a creative, flexible, critical, logical and complex thinking, like the scientific one, means to allow them to develop scientific competencies, and socio-relational ones in order to ensure a sustainable, inclusive, and equitable development at economic and environmental level. More specifically, scientific learning paths, nowadays, represent a chance to take for female students. Moreover, this perspective strength and foster a scientific and technique culture free of gender biases and stereotypes at school as well as in the workplaces. A study on the "Economic advantages of gender equity" [1] confirms how the removal of gender biases in the STEAM education could impact positively on the EU labor market so that an increase of jobs (from 850,000 to 1,200,000) and, consequently, a relevant raise of the Gross National Income (2.2 % to 3.0 % by 2050). However, the increase of women participation is slow and, following the current estimations, 280 years will be necessary to reach a gender equity.

To fasten this process, it is necessary to dismantle the false gender culture that considers the logical-scientific competencies pertaining only to men. To reach this goal, it is also necessary to motivate and engage female students in the scientific and technological disciplines through gender inclusive teaching methods.

1.2 Music in STEAM education

Among the most common uses of music in STEAM education we have the (re)writing of song lyrics to improve memorization or the use of rhythm for learning mathematical concepts [2]. Early studies have highlighted that pattern recognition is improved in auditory over visual modalities of perception [3]. The use of sound perception is obviously an essential approach in education in the case of visual impairment. Although it is not possible to define a causal link between music training and the positive effects of music on learning in other disciplines [4], individuals who have learned to play an instrument show increased capacity for concentration, memorization and psychophysical benefits [5]. In addition, a musical approach to STEAM education would help curb the cognitive and social problems associated with digitization [6].

The idea of using sound representations in relation to the description of natural phenomena has attracted many scientists over the years. An example can be found in the studies of chemist John Newlands (1838-1898), who, in his theoretical elaboration of data on the recursiveness of the properties of the elements, proposed an interesting parallel between musical octaves and similarities between the characteristics common to different elements, even before the formalization of the Periodic Table of Elements by Mendeleev. The analogy between sounds and planetary orbits dates back to Pythagoras (ca. 580-495 BCE) and was later adopted by Kepler (1571-1630) and Copernicus (1473-1543). In this representation, the Sun represents the fundamental sound of a series of sounds in mathematical relation that identify the planets. Conversely, several composers used science-related analogies in their compositions, including Paul Hindemith (1895-1963), Edgar Varèse (1883-1965) in his *Ionisation*, and Karlheinz Stockhausen (1928-2007) in *Cosmic Pulses*.

New strategies of communication of information in sound began to develop in the nineties of the last century (https://icad.org/). In recent decades, the use of non-verbal sounds (sonifications) to represent different natural phenomena have multiplied, both in science and art, increasingly reducing the gap between these two domains. The "compositional" rules underlying the sonifications are the most varied. The sound representations of scientific phenomena made in recent years include, for example, the sound of the microbiome within the project Biota Beats at MIT in Boston (www.youtube.com/watch?v=6s-x3NI8CZg&t=43s&ab_channel=BiotaBeats), or the sonification of cosmic phenomena (https://www.sciencemag.org/news/2017/07/meet-scientist-who-turns-data-music-and-listen-sound-neutron-star). To the same category belongs the sonification of DNA (http://dnasonification.org) or that of a spider web (www.youtube.com/watch?v=s4QtAQhdU2I&ab_channel=MarkusJ.Buehler). Over the years, several attempts have been made to “obtain” sounds from living organisms, often with results pleasant to the ear, but mostly unrelated to any biological signification: this is the case of the many "experiments" performed to get music from plants using electrodes that measure differences in electrical potential applied to the leaves and translate them into sounds (e.g. www.plantwave.com). The limitation of all these sonifications is the limited possibility to convey usable information at an educational and communicative level. A recent paper by Mahjur et al. [7] proposed a sonification strategy for organic molecules based on molecular properties and atom/bond arrangement, which define the key of the music and the melody, respectively. The algorithm allows to encode molecules into music and decode a music composition to generate new molecules through the interactivity of musical hardware and software.

Since 2015, some of the authors of this contribution have undertaken, as part of the activities of the Museum of Mineralogy of the Department of Earth and Geoenvironmental Sciences, a path of sonification of crystal structures. The theoretical basis of the research is based on the concept of symmetry, which is common to crystallography and music. In the first phases of the experimentation, the rules at the base of an algorithm that allows to translate the structural parameters (chemical composition, disposition of the atoms with respect to the axes of symmetry) into musical parameters (pitch, duration, intensity and timbre of the sounds) have been developed. Videos have been made that relate the images of the crystal structures to the corresponding sound effects. These first attempts formed the basis for further work. The first results were presented with an oral communication at the international conference Edulearn (Barcelona, July 2016) and published in the conference proceedings [8]. The constitution of an ensemble of about 20 instrumentalists (Earth Ensemble of UniBa) allowed the realization of some conference-concerts mainly addressed to secondary school students and their teachers. The subsequent participation, in 2018, in the international competition On the Rocks - Geological Film Festival, organized by the Italian Geological Society, with a video entitled Aural Structures, the Music of Crystals, led to the achievement of the second prize in the category (https://en.sgi-ontherocks.it/317/winners-2018.html). On the basis of these experiences, we started working on the realization of a software for automatic sonification. A second contribution was also published in the proceedings of the 2018 edition of the Edulearn congress [9]. These experiences have allowed to experiment "static" and "dynamic" ways of sonification: the realization of aural models of crystals and conduction (guided musical improvisation) as a means to transpose on the sound plane physical-chemical phenomena that are articulated in space-time. Interactive sonification modalities in classroom or museum exhibits, represent fertile approaches for education and dissemination which deserve more attention.

1.3 Exploring the potential of sonifications in education

We aim at improving STEAM education within the Italian secondary school through the development of innovative instructional strategies that can effectively embed scientific contents with the learning setting in order to improve the education quality and motivate and orient all female and male students to develop scientific careers in their university studies.

The instructional model of the sonification we are currently developing plans to mix a creative approach to the study of Mineralogy and Biology with art, music, and direct experience of students in order to support them in a participative and active learning process in the sciences domain. Our challenge is contaminating different points of view and different disciplinary approaches to develop a teaching model that is purposed to value the scientific and analytic rigor, as well as the creativity, the curiosity of students, and to increase the presence of female students in the STEAM learning careers.

2 METHODOLOGY

The Sound of Science(s) project adopts a work-in-progress approach, in which the new activities developed in the different fields of science (starting with Earth sciences/mineralogy and biology/plant sciences) are tested in the classroom using random control trials, as well as small-scale interventions, interviews, and document analysis. The general approach of this research project is evidence-based [10]: in this perspective, the purpose will be to find evidence for what works in education (i.e. sonification as an innovative teaching strategy).

Sonification strategies can be static or dynamic. In the first case aural models of scientific interest are realized linking music parameters to meaningful subjective parameters to obtain aural models (e.g. crystals, molecules, plants, cells). These models allow an active use of the sonification. In the second one, instead, the sonification is interactive and it is realized through a musical conduction or dedicated software: students play a natural phenomenon following a defined code of sonification. Among the innumerable possibilities we are currently focusing on, dynamic phenomena are potentially very amenable to an accurate and effective musical description. To name a few examples, solid-liquid and liquid-gas state transitions can be fully understood by providing a set of intuitive sounds describing the molecules and their spatial positions/movements. Similarly, the concepts of dynamic equilibria can be effectively exemplified with the active involvement of the audience. Plant biology also offers a wide range of possibilities: from the establishment of plant communities (different sounds can be associated to individuals belonging to different plant species) to the patterns of plant growth and development, including germination, leaf venation and stem cells growth.

These musical approaches are potentially more inclusive than other educational strategies because perform much the same for both scientific experts and the general public. The results obtained will be used to design a professional development model on sonification for STEAM teaching.

3 CONCLUSIONS

Our ambition is developing a “soundtrack” of natural phenomena and processes that can be used to create aural models for educational purposes. The Sound of Sciences aims at fostering institutional recognition of innovative approaches to underline the importance of science, technology, engineering, arts, and mathematics in driving innovation and scientific knowledge dissemination.

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