IL NUOVO CIMENTO **44 C** (2021) 170
DOI 10.1393/ncc/i2021-21170-x

COMMUNICATIONS: SIF Congress 2020

Teaching asymmetry in physics and art

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received 15 January 2021

Summary. — High school physics textbooks often turn their attention to mathematical and physical aspects that highlight elements of symmetry in physical phenomena and laws, skipping the key role that asymmetry has had in recent and past physics discoveries. The contribution aims to highlight how the couples beauty = symmetry and symmetry = creativity are not always well matched. The didactic path was realized in the school years 2018–2019 and 2019–2020 with a group of 64 students.

1. – Why only simmetry?

Symmetry is an organizing principle of human thought used to list, simplify, solve and better understand objects. The word symmetry has (at least) two meanings in everyday language: "symmetrical" means well-proportioned, while "symmetry" denotes the relationship between the different parts that integrate as a whole. The concept of beauty is therefore linked to symmetry [1]. Common sense makes us think that symmetry and order are equivalent, but the didactic path will show that this idea is sometimes wrong. In physics every research about symmetry, for ancient and modern physicists, was used to find what makes a set of elements the parts of a whole, connected to each other by mathematical relationships. It cannot be a coincidence that many of the greatest scientists (Galileo, Newton, Maxwell, Planck, Dirac, Einstein just to name a few) looked for symmetry in physical theories and that their works are considered unifying.

This idea appears in the majority of physics textbooks for Italian secondary education, but it is a key aspect for those who want an integrated teaching. Symmetry is a value that belongs to science, visual perception and art. It leads, however, to the impossibility of noticing variations caused by transformations: symmetry is what remains unchanged, what is preserved in time evolution. In physics and art, a symmetry is observed every time you do not realize you have made a transformation on an object. From the point of view of physics teaching, promoting the value of asymmetries is important because only thanks to them it is possible to perceive change, a dynamically perceptible alteration, measurement and existence of fundamental physical entities. This is the fundamental idea of the educational project realized with three classes of the Liceo Scientifico "B. Cellini" in Valenza (AL). The project started in school year 2018–2019 whit three classes of the 4th year and continued the next school year with the same classes, involving 64 students, 6 teachers of different subjects (Mathematics, Physics, Science, English, Philosophy and

Art) for a total of 16 hours in extra-school time. Students liked a real integration between the subjects involved and developed key skills which they used during the final exam, showing how it is important in High School to work in a multidisciplinary way. In the following sections I will describe the key ideas of the didactic path trying to enhance the didactic choices and their effect on participants.

2. – Didactic choices: Between beauty and creative imperfection

During lessons the teachers involved in the project developed with students several teaching activities: students became scientific researchers who tried to answer the question: "*In science and art, symmetry is synonymous with beauty. From this can you deduce that asymmetry is synonymous with imperfection?*". Students had were suggested to follow five conceptual points: evolution of the meaning of symmetry; symmetries, asymmetries and similarities in Mathematics, Art and natural phenomena; physical laws of conservation and symmetry; symmetries and asymmetries in Classical Physics and Art; Physics, Mathematics and Art: search for beauty or for reality? The majority of students (attending this project) got excellent results at the 2019–2020 Final Exam, I hope that the topics of the project will be part of their future cultural background and not just used for immediate didactic aims: we taught them the meaning of culture, that is "what remains after having forgotten everything you have learned" as Salvemini said [2].

2˙1. *Symmetry means evolution.* – First of all, students, divided into 15 small groups, exposed their ideas on the mathematical and artistic meaning of symmetry. Many groups proposed a definition linked to harmony and beautiful proportions maybe in reference to the etymology of the word "symmetry" (from Greek, *with measure*) and its meaning in everyday language. Some groups have instead connected symmetry with commensurability (*with measure = commensurable*) deducing how the symmetry used in Mathematics, Physics and Art has deeper philosophical roots, and can be traced back to the search for parameters of general measure and with a very high degree of abstraction. Other groups researched mathematical definitions of the several types of symmetry and took examples from artistic works. During this research students used the skills developed in High School, in particular the close link between Mathematics and Art thanks to the project "Adotta Scienza e Arte nella tua classe" [3] they took part in the previous year. Maths, Physics and Art teachers managed the last classes formalizing kinds of symmetry and proposing examples taken from the artistic world or from nature. The result was a beautiful round up of images flowing on the Interactive White Board.

TABLE I. – *The three conservation laws.*

Quantities not definable	Symmetry transformation	Conserved quantity
Absolute position (*space homogeneity*)	Translations in space	Momentum
Absolute time (*time homogeneity*)	Translations in time	Energy
Absolute spatial direction (*isotropy of space*)	Rotations in space	Angular momentum

2˙2. *Symmetries and similitudes in natural phenomena.* – In plant and animal world, symmetry seems dominant in many aspects. Lives are decided by the information contained in the genes. Generally, the gene production of symmetrical forms requires less information than the asymmetric ones. During the last lesson of the school year 2018–2019, students read and analysed some pages of the famous *On growth and form* by D'Arcy Thompson, published in 1917 [4]. Students understood that symmetry and similarity are important to describe lots of natural phenomena linked to the growth of plants and animals. In particular, they understood that bilateral symmetry is much more preferred because it is more suitable for the survival of species as it allows the movement in a straight line. In the plant world, flowers prefer central or radial symmetry, but all forms are possible, from spherical symmetry to pentagonal one, very rare in the inanimate world. If bilateral symmetry is a requirement of the animals external appearance and ensures them a great simplicity of movement, another problem of the animal kingdom are the growth conditions both of the body and inner organs. This problem is linked to the similarity principle, a counter-intuitive principle not easy to understand. To talk about this topic in a simple way, students read the famous passage on similarity from Galileo's book *Discourses and Mathematical Proofs Regarding Two New Sciences* and explored mathematical reasoning described by Galileo on the giants impossibility. Students concluded that the similarity principle [5] plays a fundamental role in evolution: in simplest organisms (under a millimeter of thickness) all functions can be performed by each cell, whose external surface is enough to breathe and eat, but in any other animal it has kept around shape and developed inner organs to increase the whole surface area.

2˙3. *Symmetry and asymmetry in physics laws.* – In the second phase of the project developed in the school year 2019–2020, students analyzed all their Physics textbooks used during High School looking for topics linked to symmetry. They identified symmetry in dynamic laws, pendulum, Galilean relativity, electromagnetism (they have recently developed the theoretical path with which Maxwell added the so-called "missing term", based on considerations of symmetry in electromagnetic equations), optics, energy and momentum. The index analysis of all their textbooks was not only a general review for the Final Exam, but also an exercise to use key skills developed in the five years of Physics course. Starting from the list of all the topics chosen by the students we introduced the Noether theorem, which establishes that in correspondence to every continuous symmetry of physical laws there is a conservation law and a conserved quantity. So from the point of view of the history of Physics, the XX century is considered the symmetry century because Noether theorem moves the study of symmetries from the artistic and mathematical world to the physical one [6]. Students' attention was then focused on the three fundamental conservation laws (table I) and their implications in terms of symmetry. In particular, we focused on the central role of the law of energy conservation and on "that act of faith" that Pauli made in 1930: he hypothesized the existence of a new particle, in order to prevent the violation of energy conservation in a decay process of an atomic nucleus. Pauli's trust in symmetry was rewarded and a few years later that mysterious object was found: the neutrino! Finally, students created (in a remote way) a laboratory on the History of Particle Physics in which they retraced (not only theoretically, but also through calculations) the steps which led Anderson in 1932 to the discovery of positron and antimatter, as already experienced by the author in [7]. Students were very interested in this experimental proposal: they had fun with Physics and liked the role of "creative" power that the search for symmetry has had in modern Physics. The last lesson of the project was inspired by this last observation.

2˙4. *Symmetries and asymmetries: Beauty or search for reality?*. – In the last lesson we tried to understand how the binomial symmetry-beauty is not always correct, using examples from Science and Art. Symmetry shows that it is not possible to see changes caused by transformation, but it is the asymmetry that creates the phenomena [8]. For example, cosmic asymmetry evolution between matter and antimatter brought the universe into the current conditions in which human life developed. The laws of fundamental physics are equally true forward or backward in time, but we perceive the time flow only in one direction: this perception is closely linked to entropy, a topic often overlooked in Physics education. Permanent magnetism is caused by the alignment of magnetic moments and induced magnetism is created when disordered magnetic moments are forced to align in an applied magnetic field. Permanent magnetism can force a symmetry, in fact higher temperatures make magnets weaker and at a critical temperature (called *Curie temperature*) magnetic material loses its magnetic properties, which can be replaced by induced magnetism. Ice is no more symmetrical than water: the chaotic aspect of water does not change under any rotation, ice changes only for rotations of 60°. In art, the symmetry inclusion is a primordial need of aesthetic nature, but asymmetry is modern, dynamic and very important in contemporary design, where information is much more important: a work appears qualitatively symmetrical until the moment in which the visual act produces a dynamic instability of the perceptual process and gives it a new meaning. Our auditory thinking is also stimulated to break symmetries, for example of the resonant modular structure of Baroque music: we feel rewarded when, after an intense and repeated effort, we manage to hear the dynamics of the ambiguity that comes from these symmetry breaks. Symmetry and asymmetry are two values that belong to science, to art perception, to our society, and also constitute moral and social values that students who took part in this project will remember for a long time.

3. – Conclusion

The didactic project was in its first experimentation and probably it needs to be improved. Students liked the use of Art. Participants' impressions were collected through a final anonymous questionnaire: many students said they have changed opinion on symmetry and consider asymmetry a social value and not only a physical one, assigning it creative and novelty power. The suggestions of those who will read this paper will be a motivation to repeat and improve the project in future school years.

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The author acknowledges Laura Armano for precious help in the English translation.

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