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On the Power of Fine Arts Pictorial Imagery in Science Education

Igal Galili

Abstract The paper describes and illustrates the potential of using pictorial artistic images in supporting teaching scientific concepts and the nature of science. In the first part, the case of Giotto's fresco of stigmatization of St. Francis is described within the interpretation of relationship between the figures as between an object and its mirror image. Educational implications of this case study are suggested. The second part presents several pictorial images that can be used in classroom teaching of science for facilitation of hermeneutic discussion in science classes addressing the nature of scientific knowledge changed in the course of history.

1 Introduction

Science education mediates between socially constructed scientific knowledge, on the one hand, and the novices and practitioners consuming this knowledge, on the other. Various tools are available to a teacher serving as a mediator and trying to represent the knowledge of science, ranging from formal analytical tools to visual graphical means (e.g., Kulvicki 2010; Vorms 2011; Michel 2013). According to developmental psychology, the stage of concrete perception precedes abstract conceptual thinking in individual growth (e.g., Flavell 1963). This fact suggests that some quantitative and qualitative changes may be necessary in the learning materials such as physics textbooks used at different levels of teaching. Typically, the more advanced the level of a physics course, the less abundant is the use of pictorial illustrations, which are considered as often less specific and fuzzier than many representations in propositional terms.

As the student advances through the learning of science, graphs, diagrams, sketches become more and more important, gradually replacing pictorial images as visualizations of knowledge representation. Eventually, abstract conceptualizations expressed in analytical equations and formulas culminate in the texts of theoretical physics (e.g. Landau and Lifshitz 1960) and its historical account (e.g., Whittaker 1951) often pushing aside

I. Galili (✉)
The Amos de-Shalit Science Teaching Center, The Hebrew University of Jerusalem, Jerusalem, Israel
e-mail: igal@vms.huji.ac.il

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visualizing elements. The only remnants of visualizing elements that can be found in advanced physics texts take the form of sketches of experimental settings (e.g. Bohr 1949/1959), symbols, such as lines of field forces to represent fields (Maxwell 1861/1965) and the especially picturesque Feynman diagrams used to represent analyitical terms and particular processes in particle physics (e.g., Kaiser 2005; Miller 1984 pp. 167–173; Vorms 2011). In general, though, most advanced texts of physics seek generality of abstract knowledge presented in universal form, free of concrete images of material objects. In fact, this feature can be used to distinguish formal texts from popular ones.

In a way, geometry muddles this distinction and illustrates the complexity of the subject. One may question whether geometry, which manipulates visually concrete symbolism, is inferior to algebraic symbolism. Descartes (1637/1954) seemingly thought that it was, and went on to invent analytic geometry as providing more inclusive statements. Even so, Descates's own presentation of physics (Descartes 1644/1983) included plenty of illustrative sketches to help readers' understanding (Baigrie 1996a). They have become emblematic of Descartes' writings.

One interesting manifestation of this question appeared in the recent discussion regarding mathematical curricula in public schools. The renowned Russian mathematician Vladamir Arnold (1998) reflected upon this in his debate with his colleagues in France. Arnold rejected the stigma of primitiveness sometimes given to visual images in mathematics. Poincare (1903) earlier explicitly stated that there were two kinds of mind among mathematicians and students: "some prefer to treat their problems 'by analysis', as they say, others 'by geometry'". Maxwell (1890/1965) had addressed a similar issue when he stated the existence of three types of mind among practitioners dealing with physics knowledge. First, there were the physicists who, as he said, master mathematical symbols, pure quantities with which to manipulate physics knowledge. Others, he continued, prefer to follow geometrical forms for the same purpose. Still others are the consumers who enjoy solving concrete quantitative problems. Maxwell concluded, however:

> For the sake of persons of these different types, scientific truth should be presented in different forms, as should be regarded as equally scientific, whether it appears in the robust form and the vivid coloring of a physical illustration, or in the tenuity and paleness of a symbolical expression (*ibid*. Vol. 2, 220).

Visual images played a crucial role in Maxwell's major contribution to physics—the theory of electromagnetism (Miller 1984; Nersessian 1992). Moreover, those scientists who resisted his theory because it drew upon the visual model of media under tension and motion (Maxwell 1890/1965, Vol. 1, pp. 451–513, 526–597) paid a heavy price by neglecting one of the most fundamental theories in physics. Thus, addressing Duhem, de Broglie wrote:

> It seems his researches on electromagnetism were less happy, for he always had a great hostility towards Maxwell' s theory and preferred Helmholtz' ideas, which are quite forgotten today. His deep antipathy with regard to all pictorial models prevented him, moreover, from understanding the importance of the Lorentz theory of electrons, then in full development, and rendered him as unjust as he was shortsighted about the rise of atomic physics, then in its beginning (de Broglie 1953).

This debate touched on the two hemispheres of the brain which are responsible for different activities: the left hemisphere—mainly processing analytic-verbal information, logic, numbers, abstraction; and the right hemisphere—operating with holistic imagery, metaphor, music (Ornstein 1975; Shlain 1991). Of course, each hemisphere complements the other. As mentioned above, however, the curricular policy starts by teaching presentations that are more pictorial and slowly shifts to abstract concepts and their codification in analytical terms. Schools do not allow visual means to be suppressed in favor of abstract forms since many students stop learning quite early, even before they arrive at the advanced abstract codification. In effect, the symbiosis of two cognitive functions, holistic and analytical, is required to master scientific knowledge professionally, as well as for attaining scientific literacy. We, thus, seemingly face a delicate problem. On the one hand, developmental psychologists state that pictorial images precede learners' more advanced abstract thinking. Nevertheless, on the other hand, we know that many bright scientific minds show a cognitive preference for visual images, which indicates that such image based thinking is popular, valid and powerful regardless of the level of psychological maturity.[1]

Let us specify the particular subject of this study within the broad area of visualization activities and tools (class demonstrations, computer simulations, using photos, graphs, schematic drawings, etc.). Many researchers have explored imagery employed in presenting scientific knowledge (e.g., Kulvicki 2010; Michel 2013) and scientists' manipulation thereof (e.g., Miller 1984; Nersessian 1992). Others have investigated the role of artistic images in science history (Baigrie 1996b). Our study, however, looks at another trend by considering possible use of works of fine arts in illustrating scientific and philosophical ideas in the process of teaching science, representing their meaning as considered in regular science classes. This specific use of artistic images has been largely ignored.

If we apply to artistic paintings the claim "pictures are basically vehicles for the storage, manipulation, and communication of information" (Lopes 2004, p. 7), we can readily bridge the gap between science teaching and art. Although art deals with aesthetics, ideas of beauty, feelings, values, as opposed to logically framed "laws of nature", art may still be relevant to learning science. This is because understanding pictures goes beyond the reading of actually represented objects (Gombrich 1972, p. 27). Artistic pictures are more than just naïve mimetic representations causing resembling to the viewer. They present "symbol systems" (Goodman 1968, p. 5). In a sense, pictures denote and depict reality interwoven with ideas; they are system-relative representations (Lopes 2004, p. 59). However, symbols used by an artist in a certain piece of art can be borrowed from anywhere, mystics, mathematics, science, etc. Accordingly, in some cases, a science teacher providing a pertinent interpretation can use pictures for educational purposes.

For example, let us take *Scenes of Nativity* by Vitale da Bologna from the fourteenth century. This picture shows an event taken from Christian mythology and which is depicted in thousands of similar works. However, the eye of an observer may catch a big detail in the center of the picture: a series of right isosceles triangles creating a sort of a fractal (self-similar) structure (Fig. 1). This detail makes this picture unique. What is the meaning of this symbol?

Several relevant sources I searched did not bring me any answer (e.g. Male 1958; Ferguson 1961; Schiller 1971; Muray and Muray 1996; Williamson 2004). The situation only changed when I asked my friend—a teacher of mathematics. He told me what it was right away: "Oh, this is a cluster of right-angled isosceles triangles which infinitely multiplies itself in similar smaller triangles just by drawing one line—the altitude from the right angle vertex"[2]. My second question to him about the possible meaning of this symbol took him more time and his answer impressed me a lot: "The right isosceles triangle—he

[1] It is believed that Einstein put it in his famous saying: "If I can't picture it, I can't understand it".

[2] This knowledge from Euclid's *Elements* was available in Europe in Latin due to several translations from Arabic in the twelfth and thirteenth centuries (Crombie 1959, p. 44).

Fig. 1 Copy of a fragment from *Scenes of Nativity* Vitale da Bologna (S. Salvatore church in Bologna). The *arrow* added points to the geometrical figure discussed in the text

said—was the first shape by which Pythagoreans—and Euclid, who considered himself a pupil of Plato—discovered for themselves the incommensurability of certain objects in nature[3]. We call this irrationality of numbers." I only summarize. Vitale da Bologna drew a geometrical pattern that for a person literate in basic geometry symbolized irrationality and infinity. Is that a powerful symbol for expressing the spiritual meaning that Christian philosophy ascribes to the event of Nativity depicted in the picture? And if so, was this a case of art borrowing tools from another realm of knowledge? In effect, this artifact points to a conjunction of different realms.

We, in science education, may keep our focus on the scientific content—the major interest of a science teacher—and still involve artistic images (Galili and Zinn 2007)[4]. In fact, when we address a pictorial image in education, often we do not refer to the heuristic image which Poincare described as "to perceive the whole of the argument at a glance" (Miller 1984, p. 233). Rather, we refer to a pictorial image which requires interpretation, sometimes lengthy and speculative. We, being oriented to educational goals, may deal with the hermeneutics of artistic products with regard to their scientific meaning.

In this article, we review artistic encoding of elements of scientific knowledge, often physics, which make the artistic image a subject for analysis by specific tools and their possible interpretations. We will exemplify this through an analysis of a fresco by Giotto, the renowned artist of the twelfth to thirteenth centuries, who allegedly used regularity of mirror imagery to codify the philosophy of St. Francis into representation of his stigmatization. We proceed to several pictorial images whose interpretation may illustrate aspects of the nature of scientific knowledge and its epistemology. Finally, we argue that these images, which are selected from many, do not only esthetically please and emotionally involve students but also effectively support science curriculum. Bridging between science

[3] See for example, Incommensurability and Irrationality at http://www.learner.org/courses/mathilluminated/units/3/textbook/03.php

[4] In the following, we will mark this publication [1].

education and art is an attempt to contribute to rethinking their relationship as called for by Frigg and Hunter (2010, p. xxvii). In following this call, this study seeks a resonance with the intellectual world of the practitioners of science education, with their cultural values, disciplinary knowledge and wish to enrich representation of scientific content.

2 Encoding Meaning Into Artistic Images by Means of Mathematics and Science

The tradition of involving art in the science curriculum started from the time science was first adopted for teaching at public schools. The pioneers drew on the values of liberal education in its broadest sense, which included art. Huxley wrote in his essay on science and art in science education:

> There are other forms of culture besides physical science, and I should be profoundly sorry to see the fact forgotten, or even to observe a tendency to starve or cripple literary or aesthetic culture for the sake of science. Such a narrow view of the nature of education has nothing to do with my firm conclusion that a complete and thorough scientific culture ought to be introduced into all schools (Huxley 1882), p. 162.

These claims were not specific and did not mention how and what to do. The idea of the art–science coexistence apparently fit the image of harmonious personality, presuming that the latter was the obvious goal of general education. Yet, Huxley hinted at something further when he mentioned that painting affected people differently in representing the "truth of nature" since the perceived truth "depends entirely upon the intellectual world of the person to whom art is addressed":

> The intellectual knowledge we possess brings its criticism into our appreciation of works of art, and we are obliged to satisfy it, as well as the mere sense of beauty in colour and in outline. And so, the higher the culture and information of those whom art addresses, the more exact and precise must be what we call its "truth to nature" (*ibid* p. 178).

Equipped with this perspective, namely, that people observing pieces of art not only enjoy sensing their beauty but also try to interpret their meaning, the underlying ideas and concepts, we may take a look into the history of relationship of artistic imagery and science, as well as mathematics. Elements of mathematical knowledge were often interwoven in numerous artifacts. Examples include numerical proportions such as the golden section (divine proportion) and Fibonacci numbers, amongst others, governed the length ratios of elements and infusing mathematical meaning into structures and pictures. The Egyptian pyramids, Greek Parthenon, medieval cathedrals, and renaissance paintings such as by Piero della Francesca and Leonardo de Vinci integrated certain mathematical models codifying their structure (e.g., Lawlor 1982; Heilbronn 1998, pp. 235–241; Vincent 2001; Livio 2002). For example, the analysis of Piero's *Baptism of Christ* reveals heavy codification of the mathematical ratio of its components (Lawlor 1982, pp. 62–63; Andersen 2007, pp. 65). Apart from causing the rationally based sensation of beauty, such design had to convey the idea of a universal order in nature and guide the observer to see the metaphysical reality underling appearance, thus testifying to the grand design of the cosmos. Contemporary observers are often unaware of this content, and not many painters of today subscribe to the claim of Luca Pacioli in his *Divina Proportiona* (1509) about the necessity of mathematical knowledge as the all-inclusive realm of human inquiry:

> A work necessary for all clear-sighted and inquiring human minds, in which everyone who loves to study philosophy, perspective, painting, sculpture, architecture, music and other mathematical disciplines will find a very clear, subtle and admirable teaching and will delight in diverse questions touching upon a very secret of science. (in Livio 2002, p. 131)

The concept of perspective avoided oblivion. Introduced in the *Optics* of Euclid (Cohen and Drabkin 1966) it returned to Renaissance painting and architecture by the effort of Filippo Brunelleschi, Leon Battista Alberti and others (Park 1997). Perspective became a standard method in art—the way to reproduce spacious reality on a flat canvas as well as on the curved vaults and cupolas. Correggio's paintings on the curved surfaces in Parma (Wind 2002), Pozzo's painting of a spacious panorama on the flat ceiling, his virtual dome of 18 m in diameter in Saint Ignatius in Rome (Andersen 2007, pp. 389–394) continue to attract contemporary scholars and amaze thousands of tourists. The comprehensive study of Andersen (2007) is an exemplar of the symbiosis of art and mathematical theory continuously proceeding in Europe from the time of Renaissance through to the nineteenth century.

Addressing the art-science relationship in the opposite direction, namely considering the impact of art to science, is also pertinent. We only mention it in passing. Art, as representing aesthetic aspects, was always involved in the appearance of scientific documents and instruments. Artisans, driven by great fantasy and clear aesthetic considerations, produced astronomical maps and instruments which served also as decoration of public and private places (e.g. Cellarius 1661; Whitfield 1995; Dekker 2004). The same can be said regarding artistic presentations of knowledge in various realms (e.g. Fludd 1617; Goodwin 1979; Margotta 1968; Evers 2006) and various scientific instruments (telescopes, mirrors, thermometers, etc.), which pleased the eye of their owners (e.g. Miniati 1991). With regard to the role of art in the scientific method, the allegation by Leonardo da Vinci was emblematic. He considered painting to be the queen of science and provided a special itinerary of scientific research, strange in eyes of many. Leonardo suggested (Wallace 1966, p. 104):

1. Close observation
2. Repeated testing of observation from various viewpoints
3. Drawing the object or phenomenon so skillfully that it would become a "fact" which all the world could see, or could grasp with the aid of brief explanatory notes.

Such sophisticated relationship between art and scientific knowledge could guide and motivate Leonardo in exploring anatomy through understanding the functions of human organs such as the neck for instance (Arnheim 1974, p. 159). His picturesque sketches elucidated understanding of ballistic and pendulum motion, optics, hydrodynamics, mechanics, etc. (e.g., Reti 1974; Argentieri 1956; Calvi 1956; Canestrini 1956). Yet, the art of today has moved beyond the photographic ideal and to a large extent the detailed accurate depiction of reality remains only in the training of artists and architects. The divine proportion between different limbs of human body remains an amazing fact inviting further research, but has largely lost its mystical flavor. The Pythagorean perception that the numerical ratio of dimensions by itself produces aesthetic impact of painting has ceased to be a convincing doctrine in our days. The special aesthetic appeal of length ratios, even if not of clear origin, is supposed to have some rational explanation, for instance, by the self-similarity (fractals) mechanism of natural structures.

Another trend of art evolved relating to natural philosophy. This combined representations of the *contents* and the *structure* of scientific knowledge using artistically prepared drawings and paintings to convey meaning:

> By admitting that it is possible to think in images, we come closer to Renaissance view of how pictures actually function, and thus to how pictures achieved their authoritative structure. For a thought picture is not necessarily either 'true' or 'false', but instead occupies a realm of its own. It is a kind of mental construct that may (or may not) be subject to whatever passes for 'rational analysis'

> within the framework of the thinker's world… This business of thinking-in-pictures is clearly not science… And yet, it is not unrelated to science either (Hall 1996, p. 36).

This genre—to represent the structure and content of knowledge by artistic means—was very popular in the past and numerous examples may be found in the manuscript *Margarita Philosophica*, a textbook by Gregor Reisch of 1517. This trend drew on the allegorical pictorial representation to create an ocean of artistic imagery deeply rooted in cultural tradition (Piltz 1981; Jung 1944/1993; Roob 2001). For example, the science of logic was represented by the drawing shown in Fig. 2a—*Typus Logice*. The picture invites a long observation and gradual recognition to reveal to the observer basic elements of logic, their application, potential difficulties, relationships and so on. These scientific illustrations were codified into a nice scene of a young hunter marching towards his future endeavors. Similarly, Fig. 2b—*The Tower of Learning*—represents in one picture the whole conception of liberal education adopted at that time including its components, hierarchy, heroes, and values.

As we can see, at all times the relationship between the arts and science was reciprocal: people tried to use knowledge about nature to make artistic representations of reality and at the same time used art to represent scientific knowledge. One may illustrate this vast topic, by addressing the topic of shadow and anti-shadow. Even the puppet theatre, common in many countries, requires basic knowledge of optics. The originally explained by Ibn al-Haytham (Alhazen), in the eleventh century, the Camera Obscura the image of reality on the wall against a small opening made his way into painting (e.g., Gliozzi 1965; Ronchi 1970). After della Porta in the sixteenth century who mounted a lens into the Camera, a prototype of the photographic camera was obtained (Porta della 1558/1957; Lindberg 1976). The often-mentioned example is the renowned Dutch artist of the seventeenth

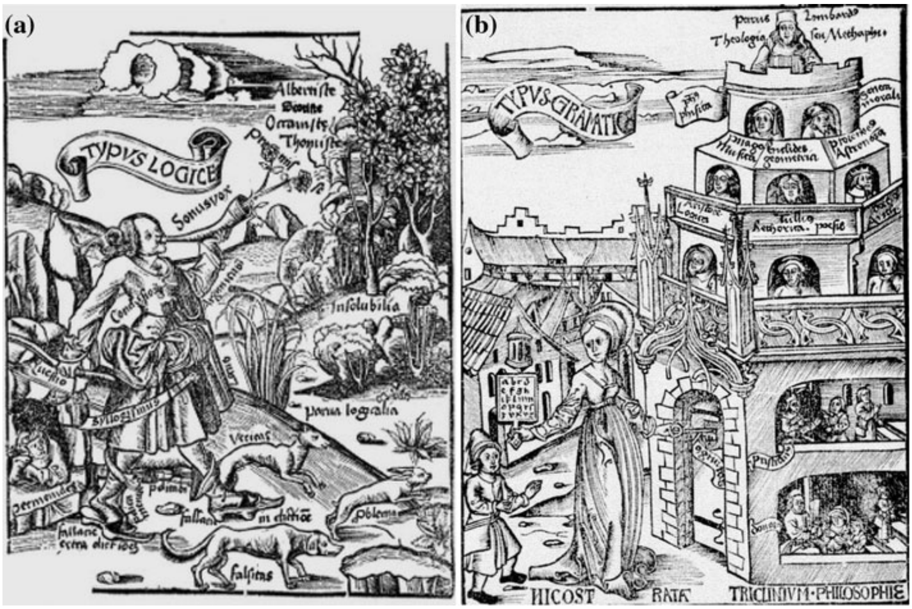


Fig. 2 **a** *Typus Logice*—The *picture* representing the structure of logic and its application in the form of pictorial allegory. **b** *The Tower of Learning* depicting the structure of liberal education in a pictorial allegory. From Gregor's *Margarita philosophica* (Freiburg, Germany, Johann Schott 1503*)*

century—Johannes Vermeer, who allegedly used a Camera Obscura with a lens to produce initial sketches of several of his masterpieces (Hockney 2001; Steadman 2002).

We, however, concentrate here upon artistic works which can be said to have some meaning pertinent to science in order to use them in class teaching of science and this may differ us from other studies considering meaning of art pieces. Very few studies have addressed paintings whose content draws upon physics knowledge (Shlain 1991; Galili and Zinn 2007; Sebestyen 2009). Shlain's study suggested interpretation of how physics knowledge of space, time, light, gravitation can be seen in modern art. Yet, addressing art works is very rare among physics textbooks (e.g. Halliday et al. 1993, 2001; Hecht 1998) and addresses only optics.

We may summarize that although scientific and artistic activities may differ in how they represent objective and subjective reflections of nature, both do seek to represent certain truth about reality (Goodman 1968, pp. 262–263). In fact, there is a continuous spectrum of cultural products amalgamating objective and subjective elements to varying degrees. Artistic products involving scientific knowledge show that science and art present two forms of intellectual appreciation of Nature in its manifestations, and that these are complementary. Adoption of this perspective in education can remove the polarization of science and art possibly attracting a wider audience to science classes. Furthermore, since "a picture, to represent an object, must be a symbol of it" (Goodman 1968, p. 5), art pieces may provide observers with new symbols of the concepts relevant for science education, involving the interpretation of art products, their underlying meaning. This role may in a way enrich art products extending their appeal beyond aesthetic and occasional associations. We have, therefore, specified the subject of this study as dealing not with straightforward scientific illustrations but with its complementary partner: interpretation of pictorial images involving aspects of physics content knowledge and features of the nature of science. We will address artistic images that were not created to be accessories for the science teacher but which still may serve as a powerful tools of intellectual expression of the subject taught in science class.

3 The Case of Giotto—Displaying an Idea by a Representative Image

In our previous paper [1] we exemplified the symbioses of art and science using situations where understanding of artistic imagery draws upon rules and ideas of optical imagery. This attitude to works of art illustrates the conceptions mentioned above relating to the artistic codification of ideas required by the observer to adequately appreciate certain pieces of art. Among the cases discussed in [1], Giotto's painting depicting St. Francis receiving stigmata was the first. We briefly repeat this interesting case and extend our analysis of it.

We try to interpret the specific work by Giotto di Bondone (1267–1337)—stigmatization of St. Francis (1300)—given that the artist himself never explained his drawings.[5] In his mission to commemorate St. Francis, Giotto invented a special conceptual framework to be appreciated against the story of St. Francis which is rather unique. Skipping the

[5] Vasari tells a legendary but illustrative story about Giotto's high confidence that his drawings can speak for themselves (Vasari 1991, p. 22). To receive the commission from the pope Giotto drew, by a single movement, a simple circle, which appearance was, however, sufficient to inform about the competence of its producer.

Fig. 3 Hand reflected in a flat mirror

details, one may mention a certain similarity of the biography of San Francesco and that of Jesus Christ. It was not, however, considered a competition but rather a reflection raised to the level of philosophy. Thus, instead of crucifixion Francis had stigmatization as the summit point of his life: echoing the wounds of Jesus in the body of Francesco. Giotto could not miss the strong metaphor ascribed to St. Francis by his closest disciple and follower—Brother Leo—who published the account of his teacher's story under the title *The Mirror of Perfection* (Leo 1227/2010) and thus developed this metaphor to be commonplace even to our days.

In effect, the need of a conceptual framework to represent the complex relationship—close similarity, yet, not equality—matches the concept of reflection in the plane mirror. Indeed, the image in plane mirror is very much like the original, but still not the same. The symmetry of the mirror reflection is special: it changes only one of the three spacious dimensions—that perpendicular to the mirror. As a result, the objects facing the mirror and located at left remain, for us, at left, and those—at right remain at right too. However, the left *hand* becomes in the mirror the right one and the right hand becomes the left, resulting in an inversion of the axis perpendicular to the mirror surface—changing chirality (Fig. 3).

For his depiction of the culmination of Francesco's life, therefore, Giotto faced the challenge of representing a metaphor of a mirror's reflection without actually showing a mirror (Fig. 4).[6] We may speculate that he solved this problem in a very inventive way—by establishing the connection between the wounds of Jesus and Francesco as may happen only in the plane mirror. Unlike few earlier depictions of the stigmatization (e.g., by Belingueri Bonaventure 1235), Giotto introduced lines precisely connecting the wounds of the two figures, one to one. Ever since, for centuries, many artists have followed him in that strategy of depiction [1]. The manner of this connection, as Giotto presented it, was special: the right hand of Jesus—with the left hand of Francis, the left hand of Jesus—with the right hand of Francis, and similarly—the left foot of Francis to the right foot of Jesus. This is exactly what happens when we look in a plane mirror: the right hand converts into the left one. Yet, the wound in the right side of the body of Jesus created the stigma in the right side of Francis's chest—no inversion. One may speculate about the reason for that and guess that Giotto wanted further emphasize the mirror idea: only hands and feet change

[6] The knowledge of optics with regard to light behavior in plain mirror (geometrical optics) was already sufficiently mature at that time (e.g., Lindberg 1976).

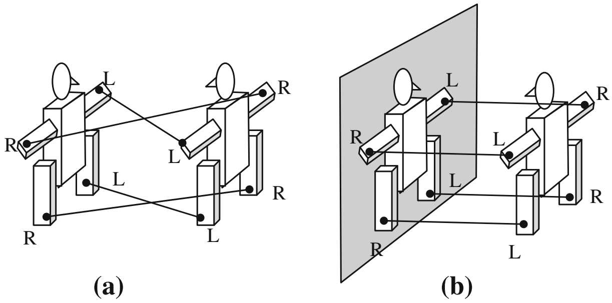


Fig. 4 Connections made between *right* and *left hands*/feet for two persons facing each other (**a**), and connections emphasizing mirror inversion as when standing before the plane mirror (**b**)

their identification, not the location of the objects facing the mirror.[7] Altogether, this interpretation might be rather complex for a naïve viewer, especially given that Giotto never explained his pictures. The price for that was that the original idea of Giotto was soon forgotten. Although numerous artists preserved the tradition of connecting the wounds with lines, but most of them "corrected" the master and thus destroyed the mirror idea.[8]

As known, Giotto produced only three signed representations of the stigmatization event: two frescos, in the Basilica of San Francesco in Assisi (1295) and in the Basilica of Santa Croce in Florence (1320), and a panel (1300), currently in the Louvre museum, Paris. In two of them, the connection between the wounds of Jesus and the stigmata on the hands and feet of Francis was made in keeping with the mirror principle (Fig. 4b). However the fresco above the entrance to Bardi chapel in the Basilica of Santa Croce (Fig. 5c) was different. The latter was painted about 20 years after the fresco in the Upper Basilica of Assisi (Fig. 5a) and the panel in Louvre (Fig. 5b). Did Giotto change his version of stigmata representation?

The ideological and historical considerations regarding Giotto's vision mentioned above may be reinforced by a similar painting located nearby—in the refectory of Santa Croce—which was produced in 1330 by Giotto's closest student and collaborator for 24 years Taddeo Gaddi. Besides the fresco, Gaddi also produced a panel painting of the event, currently located in the Fogg Art Museum of Harvard University in Cambridge. Both works of Gaddi exactly fit to Giotto's works in Assisi and Paris.[9] Following these pictures of Giotto and Gaddi, we speculated in 2007 [1] that the fresco in Santa Croce was corrected much later after its production, during several sweeping perturbations that the basilica in Florence came through (Micheletti 2007; Muray and Muray 1996, p. 199).[10] However, no argument could be compared with actual examination of the original. Visiting Florence in 2010 allowed us to validate the original conjecture due to the fortunate coincidence—the

[7] The controversy regarding the side of the chest wound of Jesus (Gurevich 1957) is not relevant here as Giotto preserved it the same in all figures. He apparently kept with the later tradition of the right side location of the body wound of Jesus.

[8] Much later, in 1630, Rutilio Manetti followed Giotto in representing stigmatization of Saint Catherine of Siena, recognized officially in 1623. Manetti, however, made the mirror correspondence between the figures complete, including the location of the wound in the chest—a rare case (Fig. 5d).

[9] Another small piece of the same event by Taddeo Gaddi can be observed in Pinacoteca Nazionale di Bologna.

[10] Emma Micheletti (2007, p. 12) wrote: "Both [chapels] were considerably restored during the nineteenth century by Gaetano Bianchi, who according to the custom of the time went so far as to restore or recreate faces, buildings and whole landscapes, robbing the great art of Giotto of much of its genuineness and original vigor."

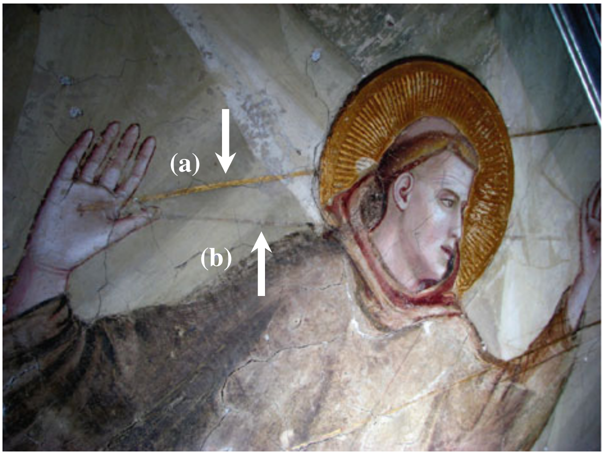
Fig. 5 Stigmatization of St. Francis by Giotto (**a**) The fresco in Assisi; (**b**) The *panel* in Luovre; (**c**) The Fresco in Florence, (**d**) The stigmatization of Santa Catharine in Siena by Manetti

restoration of the frescos in the main chapel area of the Basilica of Santa Croce. Approaching the fresco, located more than 10 m above the floor, for close observation became possible.

The close inspection of the fresco in Florence allowed in 2010 revealed the old lines of Giotto connecting the hands and feet wounds of the two images in the manner identical to the original works by Giotto and Gaddi (Fig. 6).[11] This finding placed a heavy question

[11] We may mention the amazing to the modern eye fact—the earlier frescos of the 14th century that used to cover the walls of the basilica were almost entirely destroyed by the subsequent rulers (Micheletti 2007). The walls around Galileo's tomb still bear few survived fragments of frescos of superior quality—an

Fig. 6 Fragment of the close view on the fresco *Stigmatization of St. Francis* in Santa Croce in Florence. *a* The *modern line* connecting the *hand wounds*: *right with right*. *b* Remnants of the *old line*, later *washed out*, connecting the *right hand* of St. Francis with the *left hand* of Jesus, is seen



(actually a dilemma) before the crew of experts involved in the restoration regarding the way to proceed. What lines to enhance, those of the old original or those of the later correction? By all means, the answer was not simple[12].

Furthermore, the artistic metaphor of Giotto allows one to interpret the emblem of Franciscans—two arms crossed, one representing the Deity and the other—St. Francis (both hands bear signs of wounds). This is a pair of right and left hands as in object-mirror image couple related by Giotto, rather than two right hands, which could signify unity of equal as in hand shake.

3.1 Educational Implication

Regardless of the decision to take in the restoration of the fresco in Santa Croce, one may consider possible educational implications of this case study to teaching about optical images—a concept problematic for novice understanding (Galili and Goldberg 1993). The pertinent teaching activity could be administered in classes as well as near the fresco in the basilica (perhaps in a poster for the visitors). One may use the presented story incorporated in teaching about optical imagery. The teacher may inlay the unfolding interpretation of the fresco comparing Giotto's and Gaddi's works with the depictions by other artists who, during a long history, have faced the same choice of correspondence between the hands and feet of the two figures. The idea of a mirror poses a question: what does the mirror do to the image seen in it? Does it change left to right? A comparison of Giotto's work with Manetti's (Fig. 5d), who unlike Giotto changed right to left also regarding the chest wound, may reveal additional appreciation of Giotto's strategy.

Effectiveness of teaching might be enhanced by discussing the flat mirror image in comparison with the transformations of optical images produced by convex lenses and the Camera Obscura. The four cases (Fig. 7) together may establish a space of learning, a

Footnote 11 continued
illustration of a different attitude reigned in the past, which allowed to correct and destroy. This is not the way adopted in present.

[12] After writing this paper, in our recent visit to Santa Croce in February 2013, we found that the decision was taken to adopt the presented here analysis and remove the later added lines that Giotto's fresco may receive its original appearance.

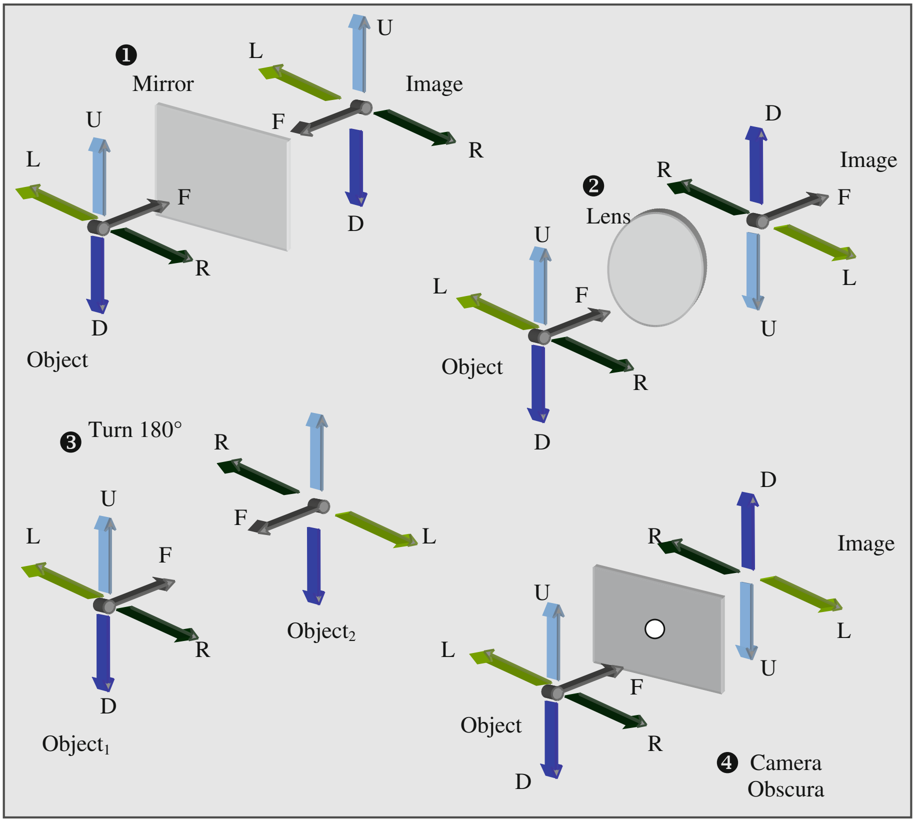


Fig. 7 Transformation of object-image dimensions in four basic situations: *1* In the *plane mirror*; *2* In the real image by the *convex lens*; *3* When two persons face each other; and *4* In Camera Obscura (no depth of the image). To share the assumed considerations of Giotto compare cases 1 and 3

representative set that may promote students' genuine understanding of correspondence between an optical image and the object through comparison between various possibilities. Extra extension may address the images in concave and convex mirrors.

4 Nature of Science (Scientific Knowledge)

The active discourse of researchers on the nature of science as taught to students usually employs and manipulates abstract ideas without any visualizing accessories. This is normal in philosophy. Education is different. Art may provide adequate images to support the ideas presented by the teacher with illustrative images which may become revealing to individuals. The span of possibilities is wide and involves masterpieces from classical and modern art. Thus, the fresco of Rafael in Vatican—*The School of Athens* (1511) may illustrate the rationalist and empiricist philosophical approaches to the scientific method (e.g. Matthews 1994), frequently presented as a pair leading to comprehension of the need for their combination in normal scientific practice (taking the form of *mathematical* and *experimental* components of science curriculum).

In the best "perspectivist" style introduced by Renaissance artists, the fresco focuses on two *equally* emphasized figures by placing both around the point of convergence (vanishing point): Plato and Aristotle—the two founders of natural philosophy and classical science. Each of the two heroes by a simple hand gesture represents the philosophical method he stated to be the correct one for the scientific account of nature: rationalism or empiricism (Fig. 8a).

This picture by Rafael has a long tradition of interpretation, including the gestures of its main heroes (e.g., Gutman 1941, Haas 2012; Phelan 2002). In science class, however, the traditional interpretation might be adjusted to be more specific. The physics teacher may address the particular debate of the two competing theories of light developed by Huygens and Newton in the seventeenth century (e.g., Gliozzi 1965). This teaching, by addressing the cultural content knowledge about light, may reveal to the students not only the ontological contest that took place between the two theories but also the epistemological one—the difference between the method of Huygens, the follower of Descartes' epistemology, on the one side, and that of Newton—the ardent opponent of Descartes—on the other (Fig. 8b). The theatrical gestures of Plato and Aristotle will then make concrete the apparent meaning emphasized in Fig. 8 by the arrows added. Plato's pointing upwards signifies the transcendental and metaphysical origin of the ultimate knowledge—the gnosis. His renowned pupil, Aristotle, challenges Plato pointing down, to the earth, with a gesture that moderates the metaphysical ideas of his teacher, suggesting the opposite foundation—human experience and contemplation as the true and reliable resource of the theoretical knowledge about reality.

The teacher may extend this discussion by mentioning another fresco of the same artist, facing *Scuola* from the opposite wall of the same room—*Disputa*[13] (*Disputation of the Holy Sacrament*). Rather similar in being a collective "portrait", the two pictures are different in arrangement and gesturing: Disputa has a single central figure of a scholar (next to the central sacrament) and no controversy in gesturing (he points up). By juxtaposition of the two frescos facing each other Rafael, thus, shows the essential epistemological difference between science and religion (regardless of the context or ontology): unlike religion, there can be no single authority in science preserving its eternal dialectic discourse of opposites.

Furthermore, below the *School of Athens* fresco, Rafael makes much smaller and more modest, colorless frescos depicting the *Siege of Syracuse* and the *Death of Archimedes*. Why just Archimedes out of all the many heroes and events in the history of science? Is that a representative/emblematic case of scientist-society relationship? Again, we may only guess (and use our guess in teaching science!) as to the intention of this genius artist showing himself in this room of the Vatican as an impressive intellectual.

Raphael's *Scuola* is very powerful indeed for long observation and discussions, but it is not unique in its representation of the subject of the nature of science. Plenty of other examples are apt for representing the two basic poles of the scientific epistemology, Platonic rationalism and Aristotelian empiricism. For example, a pair of pictures by Botticelli and Caravaggio (Fig. 9) used together, may well hint on the same opposition of the two basic epistemologies. The a priori nature of the basic claims of a theory, their plausible and even obvious superiority over the false alternative, becomes a subject to infer from observation of two allegorical figures in the Sandro Botticelli's *Calumny* (1494), from Uffizi gallery in Florence. The picture suggests that truth is apparently different from falsehood and a well-educated person has no problem distinguishing between the two and cannot be deceived. Botticelli chose a nude figure to be the allegory of truth and contrasted

[13] See for example in http://en.wikipedia.org/wiki/Disputation_of_the_Holy_Sacrament

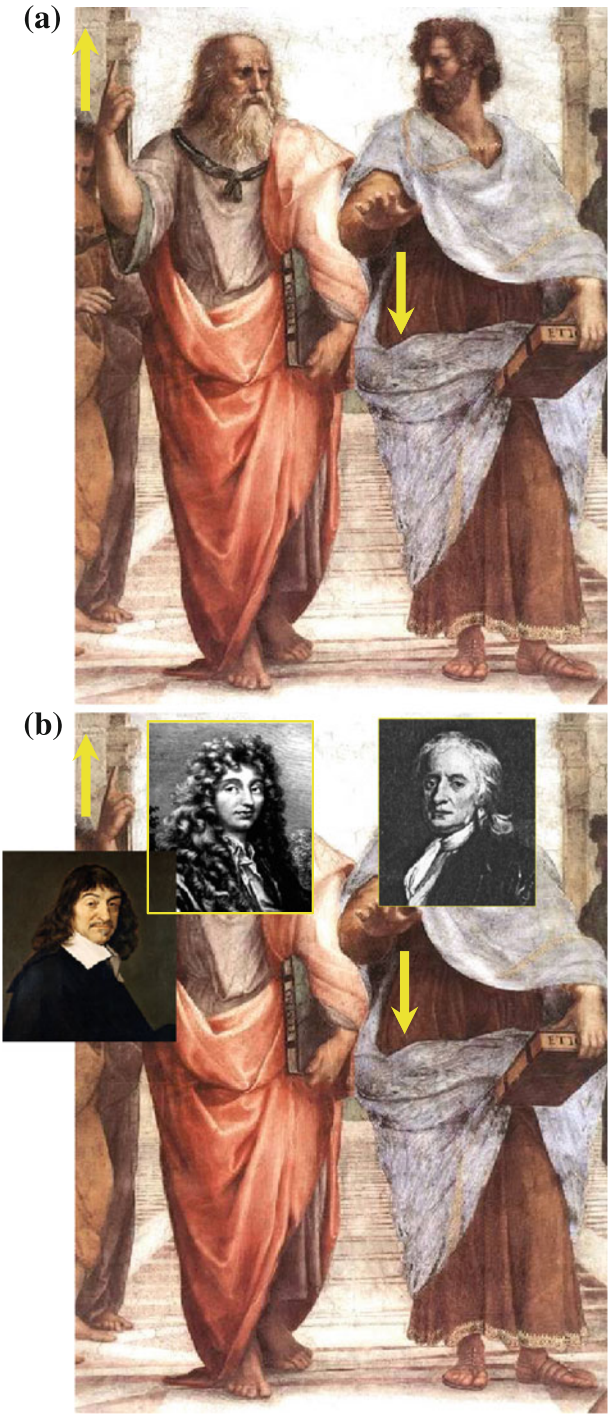


Fig. 8 **a** Fragment from the fresco *School of Athens* by Rafael Sanzio (1511). Plato and Aristotle represent, in effect, the rationalist and empiricist philosophies of science (*arrows* added to emphasize the gesture). **b** The *same picture* modified in the course of class teaching regarding the debate on the nature of light between Huygens and Newton. Descartes' portrait was later added to the *same slide* to mention the contribution of Descartes to the rationalist approach to the scientific enterprise in the seventeenth century

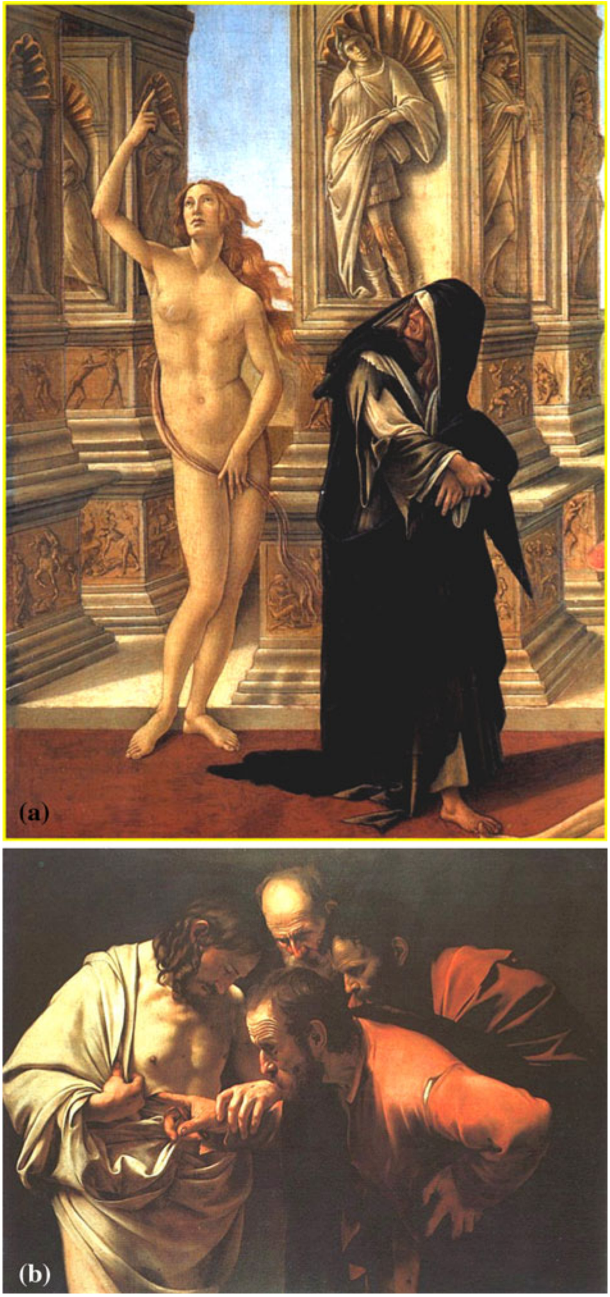


Fig. 9 Two artistic images of possible use for illustration the ideas of Platonic rationalism and Aristotelian empiricism. **a** A fragment of Botticelli's *The Calumny of Apelles* (1494). **b** Caravaggio's *The Incredulity of Saint Thomas* (1602)

it with falsehood completely covered with cloth. Why?—may the teacher ask students and lead to a discussion reviving the original and essential idea of the Greek founders of natural philosophy—that nature is open[14] to adequate comprehension through theorizing on reality which is effective due to the unconcealment of nature (Heidegger 1977, pp. 160–161, 166). Greeks applied a kind of very careful observation combined with theorizing—contemplation. From there, to Plato's 'vision of truth', identified with good and beautiful, perceived though adequate reasoning (for instance, by geometry) despite of deceiving senses. Eventually, this discussion may arrive at Einstein's 'Subtle is the Lord, but malicious He is not' (Pais 1982, pp. vi, 113) from which the same Greek optimistic idea of possibility to see the objective truth about nature continues to twinkle.

Yet, not to oversimplify the subject and return to the material more familiar to students of physics, the teacher may mention Descartes' advocacy of his entirely wrong theory of collisions of hard bodies based upon the principles he took to be indisputably correct (Descartes 1644/1983, p. 69)[15].

No less strong is the picture by Michelangelo Caravaggio, *The Incredulity of Saint Thomas* (1602), from the Sanssouci museum in Potsdam. Although, the context is again taken from the realm of the Christian religion, the idea is certainly universal. The researcher shows unlimited curiosity in seeking as much reliable evidence as he can get his hands on, quite literally. Thomas looks for sensible evidence that surpasses a mere appearance: Thomas's finger does not merely point to but penetrates into the wound! This is beyond mere seeing. Despite the purely religious context of the event, the idea of seeking the empirical evidence as being the superior and only reliable source for knowledge can be readily related to the empiricist (positivistic) epistemology of science. Does the picture bring to mind that the in vitro approach of investigation[16] ("interrogation of nature by experiment" as often ascribed to Francis Bacon) is preferred to the in vivo one? This artistic image has such a strong affective impact that it may effectively contrast the rationalist call for an a priori postulated principle, even if that would appear obvious.

The teacher may introduce here the positivistic critique by Mach with respect to Newton's definition of mass as a "quantity of matter" (which is still in use in textbooks). Mach criticized this definition because of its declarative quality. Mach suggested a new *operational* definition of mass, instead of the dubious determination of the amount of matter (Mach 1883). Similar examples can be taken regarding the operational definitions of simultaneity in relativity theory (Einstein 1905/1923) and other concepts in physics, for instance, the concept of weight as debated in the teaching of classical mechanics in our days (e.g. Marion and Hornyack 1982; Galili 2001, 2011).

One may again mention that all these suggested paintings were not produced for teaching science in our classrooms. However, they can become a suggestive background having strong aesthetical and emotional appeal, triggering constructive discussion in hands of the informed teacher.

Discussion of the nature of the physics knowledge need not, however, stop at these two classical epistemological trends but may expand into the issue of the modern versus the

[14] Openness, more precisely "unclosedness" or "unconcealedness", of nature in view of pre-Socratic Greek philosophers presents their concept of aletheia. Although criticized for modern identification with "truth" (Heidegger, Heiddeger 1972, p. 70), unclosedness presents the fundamental precondition of the scientific truth.

[15] This case was discussed by us in length elsewhere.

[16] In vitro is usually associated in biology with the death of the subject of investigation when it becomes an observable under the microscope (imagine a mosquito between the glass plates).

Fig. 10 The characteristic side of the Nobel Prize medal for physics (from the medal belonging to Albert Einstein). *Two allegorical figures* represent the nature of scientific activity perceived in the nineteenth century as reflecting the fundamental epistemological belief of the classical physics (Names of the figures on the medal are emphasized)

classical physics doctrines of objective reality and its comprehension. This may touch on the epistemological revolution that appeared in the science at the beginning of the twentieth century. What artistic image could one choose for that illustration?

To represent the epistemology of the classical science, the teacher may use the image of the Nobel Prize medal for physics (or chemistry) which on its reverse side contains a scene of two allegorical figures (Fig. 10). The two female images represent Nature (Natura) and Science (Scientia)[17]. In an extremely careful and gentle motion, Scientia uncovers the veil revealing the face of Natura. The image clearly transmits the idea: nature has its own veiled features which are entirely independent of an observer, it is the scientist, in a general sense—an observer, who discovers these objective features of nature. This claim is strong: Scientia looks at nature from below, but Natura, above, remains entirely indifferent. She looks forward, neglecting her investigator. The veil, the lightest possible material, hints on the utmost effort of the investigator to minimize the disturbance caused in discovering the objective truth about nature, which is unique and beautiful in appearance.

To appreciate the change which has taken place in scientific epistemology, one needs to compare the image of Fig. 10 with a contrasting alternative pertinent to modern science. The complexity starts, however, with the fact that more than one aspect of science went through a cardinal change on the way to modernity. Yet, the common feature of this modernity, shared by all its various aspects, is the role of the observer.

The theory of relativity states that we can account for reality only through universal laws which possess a form independent of the observer, of frame of reference (covariant form). Yet, various aspects of reality, including such fundamental ones as time, space and simultaneity, may appear differently to a variety of observers (each in his own frame of reference), while others, such as speed of light, charge, (rest)mass, are world constants and remain universal, that is, they remain the same for all. One may find an echo of these ideas of the newly revealed order of things in the interpretation of some pictures by Picasso.

[17] In other languages, the two female figures might become an inappropriate choice. Thus, in Hebrew, both terms are of masculine gender, seemingly reflecting a different philosophical and traditional perception of Nature in Judaism.

Fig. 11 **a** *Portrait of a Women* by Picasso. **b** *Portrait of Picasso* by Juan Gris

In a departure from classical art, Picasso, seemingly influenced by the ideas of the new physics, tried to depict the appearance of certain subject from more than one perspective simultaneously (Fig. 11a), hinting on accounts in different frames of reference, but still keeping with the same personality—invariant in essence.

Another feature of modern physics is the crucial role of the observer in determining the state of the object from the micro-world of elementary particles (e.g. Heisenberg 1958, pp. 44–58). The essential dependence of the micro-object being measured with macroscopic apparatus can be compared to the crucial dependence of the appearance of the subject depicted in the picture on the artist—the creator of the portrait. The latter is very different from a photographic reproduction of the subject (e.g., Fig. 11b). Yet, it remains the same object. Thus, when we observe a portrait produced in the cubist style, we are forced to think about the artist, his intention (what did he want to say by this and that?) and his feelings (was he positive? did he like that?). This aspect becomes not less and even more important than the object itself (who is depicted?). Yet, we can/should recognize the person, that is, the subject still possesses his identity, his essential features. This aspect of the cubist style may be compared to the major feature of reality described by quantum theory. In particular: the macroscopic object determines the state of the microscopic object, but the extent of options of the result is limited by the nature of the subject: not everything can be changed and not in any way, that is, the subject preserves its fundamental features (mass, spin, charge, etc.).

The situation is not like an X-ray "portrait" of a human arm, for example. X-ray image depicts the subject as it objectively is even if it is not seen by us in that particular way. We cannot observe bones covered by flesh and skin through which visual light cannot penetrate. Yet, X-rays can. Inspecting regular X-ray pictures, we never think about the technician who made them, as he didn't change anything in the object, the arm. Similarly, pictures seeking photographic similarity between the image and the object may push the artist into the shade: we focus on the object as it is. This is the vision of classical physics, as we discussed with regard to Fig. 10 with respect to the role of the researcher. Similarly to the researcher in quantum theory, the cubist depiction treats the object aggressively moving the artist (the researcher, his apparatus) to the fore. Although the actual person posing for the portrait, could be recognized, the real subject is the portrait itself, not the photographic image of the person. The active, disturbing, and unavoidable intrusion of the artist into the subject is similar to the researcher into the micro-world and the *portrait* is like the micro-object; influenced but nevertheless preserving its object and possibly emphasizing its certain features. This analysis of the roles of the artist, the portrait, and the person depicted can take place in the class while introducing the meaning of quantum theory of reality.

Furthermore, science teachers may, and do, address the complexity of the relationship between nature and its account by science through production of theories. On such occasions, teachers may say that scientists do not just reflect and reveal, but rather construct and invent scientific knowledge. The modern rhetoric regarding science education widely uses the term *construction* (sometimes *reconstruction*) of knowledge, rather than its *adoption*. Thus, ideas of revealing and discovering often compete with ideas of inventing and producing. In such discussions teachers may appeal to the famous Aristotelian research cycle (e.g. Losee 2004, p. 5) as refined by Einstein (1952/ 1987, Fig. 12a), who mentioned the irrational move from experience (E) to fundamental axioms (A) and the rational deduction from axioms (A) to deduced statements (S). In science class, one may place this discussion on the fertile allegorical ground of the ancient myth from Ovid's *Metamorphoses* about Pygmalion and Galatea and use its artistic presentation (Fig. 12b). This didactic move may concretize the non-trivial subject and trigger the required analysis.

Pygmalion—a young sculptor in Cyprus—disappointed with his environment, produced a sculpture of an ideal woman and fell in love with it. The goddess Aphrodite, however, was gracious to him and with a breath of life converted the stone into a living woman. The new couple was happy. This mythological story inspired many artists who in their pictures focused on the idea of the human ability to compete and even challenge nature in creation of beauty: humans possess a special "Pygmalion's power" (Gombrich 1972, pp. 93–115). Numerous artists who depicted this myth have focused upon the beauty of the product—the human body (e.g., Agnolo Bronzino of 1530, Jean-Léon Gérôme of 1890 and many others).

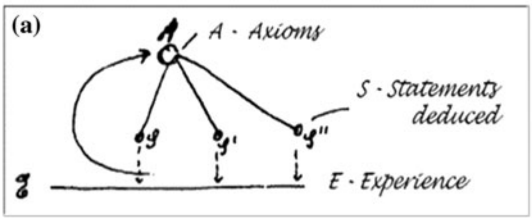


Fig. 12 **a** Reproduced sketch by Einstein's of the scientific method. Irrational creative leap from experience to axioms is parallel to artistic inspiration. **b** *Pygmalion and Galatea*

Very few artists have, like Francisco José de Goya, put the act of construction to the fore, the hammer and chisel—hardly seen in other pictures—by which the sculptor transferred the dead stone into a beautiful object. It is the latter artistic version that the teacher should bring to the science class to support the debate of formatting, molding and constructing the scientific theory in the act as different from revealing and discovering that which already exists. For example, such discussion may consider whether Newton invented or discovered his law of gravitation.

If Pygmalion is identified with a scientist creating the knowledge of nature, then, Galatea represents this knowledge—a theory of nature. Is the product arbitrary (as some might claim)? Not at all, as the myth shows. The teacher may ask and the students may come to see that Pygmalion actually constructed a regular woman, not something abnormal. A woman such as he could have met, if not in his own village, then, after a little travelling. This trend may lead to a realization of the objective nature of scientific knowledge and to an illustration of the normal belief of scientists in the objective essence of the knowledge about nature that they have actually constructed themselves despite the idiosyncratic views and special circumstances which vary in time and place. The story of Pygmalion symbolizes not only a specific success but informs us about the nature of this success.

Is the scientific knowledge produced in this way unique? The answer is negative. As we all know, the body of scientific knowledge is comprised of several subjects (physics, chemistry, biology, etc.) and each of these is itself constructed from several fundamental theories. Thus, physics, for example, includes such fundamental theories as classical mechanics, electromagnetism, thermodynamics, and quantum theory each addressing a different facet of reality and a different kind of phenomenon. It appears that science produces several pictures of the world, several perspectives with which people represent the same objective reality using a specific kind of sophisticated account.

This subject may be illustrated by the artistic allegory of a choir of singers depicted in Van Eyck's *Singing Angels* (1429) (Fig. 13a). The idea *one source—many voices* is apparent there. The angels sing from the same Book and the teacher may mention here Galileo's "Book of Nature" (Galilei 1623/1957). The perceptions and performance of the singers apparently vary; yet, they keep with the same subject and melody. Also, despite of the difference of faces, the angels also look similar. This image may serve as a background to a discussion introducing the big picture of physics. Comprised of different, sometimes very different, fundamental theories, the disciplines still share a similarity and a family resemblance (Wittgenstein 1953/2001; Tseitlin and Galili 2005; Irzik and Nola 2010); they possess a common genus. What is it?—objectivity, cumulative, distributed and self-correcting nature? The concept of a cultural content knowledge being infused by revealing the discourse of certain physical subjects (Galili 2011) can be related to the same discussion of the multiplicity of different and similar scientific accounts.

Why does one need this discussion in science class? In answering that question, one may present the picture of a maze placed by the designers on the floors of some cathedrals (Fig. 13b). Why place a labyrinth in a temple[18]? Is that a mere decoration? Discussion may reveal the effectiveness of looking from a raised perspective when facing complexity. In science education, this would relate to providing the learner with the big picture of scientific knowledge. The labyrinths on the church floor are also beyond artistic decoration. They convey the idea that people's lives and problems—being as complex as they

[18] In this presentation, there is no need to distinguish between labyrinth and maze.

Fig. 13 **a** Van Eyck's *Singing Angels* (1429) from the Altarpiece in the cathedral of Ghent. **b** Labyrinth on the floor of the cathedral of Amiens

are—when observed from a certain position, from "above", provided in the temple, may become clearer. The apparent complexity can become comprehensible and resolved[19].

5 Discussion

The images discussed here have been used, among others, throughout the last decade in a course for graduate students in a science-teaching department of our university. The course reviewed and discussed the involvement of the history and philosophy of science in science teaching, practice and research. Students' reactions was normally very positive. The appearance of artistic images during the lectures dealing with disciplinary knowledge and the reference to them in discussions changed the environment usually limited to textual slides, references, graphs, and tables. Artistic images changed the character of the discussions. The appeal of the envisioned idea was strong and often complex, open to a variety of possible interpretations. Seemingly for that reason, students often insisted that the lecturer provide his interpretation, although they often had their own. The interpretations competed and together triggered discussion on the subject of the material to be covered in the lecture.

The first experience of using some of the images with high school students was obtained in 2010 with lectures given in two schools (*Liceum Scientifico*) in Rimini (Levrini et al. 2012, 2013). The lectures reviewed the knowledge of optics as developed through the history—four fundamental theories of light from Hellenistic Science to the Modern Physics

[19] Some sources mention the old tradition of labeling the mazes in Cathedrals by "The Road to Jerusalem" as if suggesting the same idea—it might be difficult on the way of pilgrimage (or learning) of the believer but those who reach Jerusalem (or become properly educated) obtain the from-above perspective, which simplifies vision of the truth about being.

(Galili 2013). An especially strong impact was registered from comparing the Fig. 10, as representing the rationale of the classical physics with Fig. 12b—for the modern approach. Students and their teachers reflected to the lectures and eagerly expressed their views in discussions and interviews (Levrini et al. 2013). The comparison of the two pictures was powerful in triggering discussion, revealing confusion and preconceptions matched by curiosity regarding the relationship between physics knowledge and the real world.

The issue of artistic images apparently touches upon the cultural tradition. Indeed, most of the images considered here belong to the Western cultural tradition and may become problematic in a different environment. However, since the benefit of visualization of abstract ideas is universal, as well as the various features of the scientific method adopted in all countries around the globe, the possible reluctance to the specific images for any reason merely indicates a need for different images, closer to the world of the learner in order to represent the same ideas. Indeed, art of different nations has developed in different ways and has produced different products. Nevertheless, these can address abstract ideas touching on the knowledge about the objective reality in the language of a specific artistic tradition. For example, using Yin-Yang image as signifying a solution for the controversy of Fig. 8 and leading to complementarity in scientific epistemology was enthusiastically met by the audience familiar with this image from their own culture[20]. One may also be reminded of the use of this image by Niels Bohr as a powerful representation of the idea of quantum theory.

People commonly ascribe to certain artistic images the power of representing concepts: Botichelli's Primavera—for love and beauty, Michelangelo's David—for force and courage, Carpaccio's St. Augustine's—for revelation, and Grunewald's crucifixion—for suffering. They became imagery archetypes. The oral literature in the dawn of history (fairy tales and myths) inspired the creation of emblematic images identified with national folklore, crafts and toys. Similarly, science educators may involve certain images for their purposes—to facilitate students' initial thinking about abstract ideas of science. Such images fixed in memory may furnish and support an initial acquaintance with abstract concepts of science and hint on the nature of scientific knowledge. Without such images, teachers' formal comments relating to this complex subject—all they usually have time for in a regular physics teaching—have a big chance of being left without reflection.

Yet, the issue of pictorial visualization is far from trivial. Exactly like the widespread use of analogies in teaching physics (electrical current as a stream of fluid or gas, light as water waves, etc.) the suggested image may give an idea, but may also mislead. Nevertheless, just as analogies which remain in use, because they provide an idea, or gestalt, that serves as an anchor for a more specific thinking about the subject, so may the artistic images. They infuse a certain provisional view instigating further consideration, refinement, and analysis. It is upon the teacher to promote the following cycles of interpretation: to suppress the foreign and encourage the desired aspects of the initial interpretation. Pictorial images are not a mere theatrical scenery of the lecture (there is nothing wrong in that either). Appropriate images may trigger relevant discussion, elucidate and convey an unexpected idea, not even considered otherwise by the learner. Images, after being observed and debated, are remembered together with their new interpretations, simplifying the memorizing and retrieval of the important contents of the taken course to many individuals.

Another reason for their use is that artistic images affect the observer not only by meaning but also by their esthetic appearance, the deep admiration people usually express

[20] The lectures using artistic images were given in China and Korea.

Fig. 14 Student at lecture by Jacobello and Pierpaolo dalle Masegne (1383). Fragment from the relief on the sarcophagi of a professor in Bologna museum of the medieval history

in museums and galleries. Observing our students at the lectures in which the artistic images by Giotto, Rafael, Caravaggio and other masters were presented, we could reveal that teaching involving such "strong" art pieces may receive sympathy for their making an abstract idea somewhat concrete, and even pleasing. Meaning and appearance, when combined within an affective appeal, cause a special feeling of pleasure of understanding radiated from students' faces. As photography of such moments is problematic, we may illustrate our experience in this regard with the relief of a student from the medieval sarcophagi of a university professor in Bologna carved by Masegne brothers in the fourteenth century. For its extraordinary expressive power, this artistic image became widely accepted in Bologna as emblematic of the superior pleasure of learning when it is accompanied with understanding (Fig. 14). We saw such faces in the flesh when observing the artistic images brought to the physics class.

6 Concluding Remark

Using pictorial images of abstract concepts in science education accompanied with interpretive discussions may change the appearance of science teaching and appeal to wider population of students than normal. This topic touches on the dialogue between the arts and sciences (Frigg and Hunter 2010), which is diminished in contemporary research of science education. In this paper, we have addressed several artistic images suggested for facilitation of pertinent discussions throughout the course of regular teaching. Scientific knowledge can be involved in the art pieces in codifying their meaning by the artist who expects the observer applying that knowledge. With regard to physics knowledge, this situation was exemplified by the fresco of Giotto in Florence, which was corrected because the codification idea of the artist was missed. We argued about the potential of this case for teaching of optics. As artistic images are not produced for teaching science, the role of a teacher cannot be overestimated. It is the teacher's responsibility to introduce, bring attention, and facilitate the initial interpretation by the students. Several of the artistic images discussed above address different audiences and different levels of disciplinary instruction. Images have to be adjusted and tuned to the particular educational context, curriculum, cultural environment, and knowledge background of the audience.

A special power of artistic images may help introduction of abstract ideas regarding the nature of scientific knowledge and the method of its production. Like the use of allegory in painting and the use of analogy in explaining physical phenomena, the artistic product may successfully appeal if supported with teachers' elaboration, questions and discussions. Appealing through several channels (non-scientific context, allegorical simplification, and aesthetic appearance) and supported by hermeneutic pedagogy, artistic images may enhance students' conceptual knowledge. Only a few first steps have been made to investigate the impact of such pedagogy upon various dimensions and more research effort is required. Our initial experience has testified to a positive resonance on behalf of teachers and students in science classes.

Acknowledgments It is a pleasure to express our gratitude to the rector of the Basilica of Santa Croce Padre Antonio Marcantonio who allowed us to approach the discussed fresco and gave his kindest support in our attempts to clarify the status of Giotto's fresco in the Basilica. Writing this essay started following the lecture prepared for the Colloquium of the Australian National University—'Art and Science: a symbioses leading to the appreciation of both as a pluralistic culture in science education' on August 12, 2011. The lecture was stimulated by the interest, invitation, and inspiring discussions with Professor Sue Stocklmayer at the Centre for the Public Awareness of Science of the College of Physical Science, whom it is our pleasure to thank.

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