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Physics and Art – A Cultural Symbiosis in Physics Education

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Abstract. This paper presents and discusses examples of works of art which, if included in science curricula, could prompt an understanding by students of some concepts in optics through a discussion of the context in which they were created. Such discussion would elucidate the meaning of the artworks and, at the same time, challenge students' misconceptions, attracting their attention to the scientific aspects of the art works concerned. This type of learning represents a culturally rich approach to modern science curricula. The simplified contrasting of science and humanities is criticized.

1. Introduction

At first glance, science and art appear to be areas of human intellectual activity which are essentially different in nature. Thus Shlain (1991) depicted physics and art as opposites:

> The physicist, like any scientist, sets out to break nature down into its component parts. This process is principally one of reduction. The artist, on the other hand, often juxtaposes different features of reality and synthesizes them so that, upon completion, the whole work is greater than the sum of its parts.

However, many examples testify to the complementary relationship between these domains. Perspectivists such as Alberti and Botticelli, in the flourishing art of Renaissance Italy, applied principles of Euclidian geometry to paintings (Park 1997). Other Renaissance artists, such as Piero della Francesca and Rafael, arranged their figures in paintings in a sophisticated way using the golden section ratio, spirals, double squares and other mathematical concepts (Lawlor 1995). Correggio painted on the curved surfaces of domes using sophisticated geometrical concepts to achieve correct proportions and the impression of space and voluminous figures (Wind 2002). Following Leonardo, who studied penumbra using light rays to account for and represent grades of light and shade in his pictures, La Tour and Caravaggio focused on the representation of light sources and discovered the contrast of illuminated objects with a dark background. Vermeer, by trial and error, achieved the desired panoramic effect of painting by using camera obscura (Steadman 2002).

The above examples, however, represent the use of science in the service of art, improving the arsenal of representation tools. In this paper we discuss the relationship between art and science from another point of view, viz. the way in which both disciplines fuse to express some cultural (philosophical) idea. We interpret this cooperation using a semantic approach. We discribe three artistic presentations in which physics concepts and understanding, as well as ideas of a theological or philosophical nature, have guided the artists. We believe that such a symbiosis may appeal to students who show no interest in physics when it is presented as a formal, mathematically elaborated discipline, divorced from the humanities.

2. Conceptual Background

To clarify the relationship under discussion, we employ semantic approach introduced by Frege (Frege 1892; North 1995). He considered a triad of (1) an object, (2) the sign which denotes it (its name) and (3) the concept which explains the sign and provides the meaning of the object within a certain culture (Figure 1).[1]

For the purpose of the present discussion, we expand this account by regarding Nature as the object. We suggest Science as its sign because natural science treats Nature as its subject by developing and presenting theories of natural phenomena. Science signifies reality, depicting it by ascribing cause–effect relationships to the natural phenomena. The union of scientific principles conceptualizes Nature and explains its scientific account. We thus arrive at a semantic triangle which represents human scientific endeavor regarding Nature (Figure 2). An important feature of this construct is our belief/conviction that that scientific knowledge purports to be *objective*, i.e. although it is created by human imagination and intellectual power, and draws on experience and previous knowledge, in its hard core it is independent of personality, individual will and mood. Its products seek universal validity, should be reproducible by anyone on demand under precisely determined conditions.

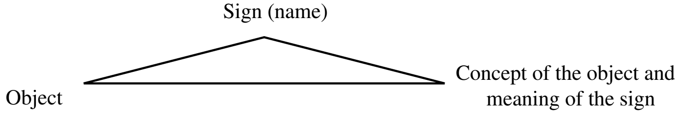

Figure 1. Semantic triangle.

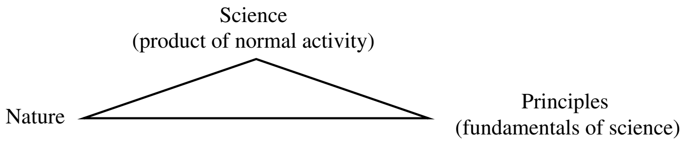

Figure 2. Semantic triangle of objective knowledge of nature.

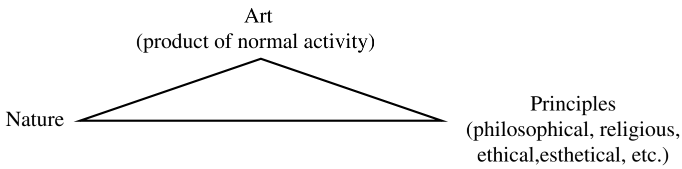

Figure 3. Semantic triangle of subjective knowledge reflecting nature.

For the second stage of our discussion we retain Nature as the object, but consider Art to be its sign. This is justified because Nature is the object for many artistic creations within numerous styles and conceptual frameworks.[2] Art, of course, is not objective but inherently subjective, representing reflection through the prism of individual emotions, sensory associations, and feelings. Talented individuals have developed various styles of artistic expression corresponding to different cultures. Pleasing observers by esthetic aspects, however, does not exhaust the meaning of artistic products. In fact, throughout history, artists in one way or another addressed general ideas, trying to express, illustrate and interpret a wide span of principles of a philosophical, religious, moral and ethical nature. These two layers of art appeal are parallel to the two functions of scientific knowledge represented by two vertices in the semantic triangle of Figure 2 (products of normal activity and fundamental principles). Therefore, a similar semantic representation is possible (Figure 3). The difference in this latter case is that the obtained semantic triangle represents subjective knowledge.

The two semantic triangles signify nature in different ways. They show that science and art express two forms of intellectual appreciation of the same subject, Nature. The two are often considered as a pair of opposites. However, there are many examples in which these two types of human activities merge. There both manifestations of the human intellect interweave, each making use of the concepts and tools developed by the other. Such cases may be valuable in a curriculum which seeks a broad cultural scope.

The integrating approach is valid also because any signifying of nature by an individual naturally presents a certain combination of objective and subjective aspects of knowledge. For example, in mathematics, the fractal pictures of Mandelbrot combine valuable information about certain mathematical objects with their aesthetic perception by a viewer, and in modern art, many pictures of Magritte challenge common sense, provoking objection and thought. In some cases (such as Escher's works) art and science are so interwoven that it is difficult even to identify the work as belonging to science or art (Ernst 1978). The use of such cases in science teaching may help removing confrontation of art and science, so that an awareness of science and art as two complementary and mutually supporting methods of viewing and understanding nature is introduced. The approach is in contrast to the common practice of dividing students between science and humanities streams already in school education, presenting two mutually exclusive options different in both interests and contents. The commonly employed educational approach often corresponds to the obsolete framework of "the two cultures" (Snow 1961), and is not consistent with the present cultural atmosphere (Tseitlin & Galili 2005).

3. Examples

We now present some examples of art in which scientific and humanistic ideas co-exist. The particular knowledge required for interpreting them suggests their possible incorporation into teaching of particular scientific topics, as well as into art classes when representing the process of artistic creation.

3.1. THE RECEIVING OF THE STIGMATA

The story of St. Francis of Assisi (1182–1226) receiving the stigmata is recounted by his biographers, Celano and St. Bonaventure. This highly dramatic event of 1224 belongs to the canon of the Catholic Church and has attracted the attention of many famous artists, starting with Giotto. According to Christian belief, St. Francis received a vision of Christ nailed to the cross. This was followed by the mysterious appearance of five wounds on the body of the saint, replicating those of the crucified Christ. In portraying this event, several artists drew lines connecting the wounds of St. Francis with those of Jesus, pointing to the correspondence of wounds passing from one body to another.

The problem for each artist depicting the event was how to connect the wounds: left hand to left hand (and right to right) or left hand to right hand (and right to left). Books on iconography (e.g. Ferguson 1961; Schiller 1971) do not address this problem. However, a scientific analysis might be revealing.

If the artist perceives the meeting of St. Francis with Jesus as that of two persons facing each other, then the lines connecting the stigmata would have to cross, as shown in Figure 4a[3]. Giotto, famous for his depiction of St. Francis in frescos at Assisi in 1290, apparently did not think that way. In his fresco representing the stigmatization the left hand of St. Francis is connected to the right hand of Jesus and vice versa (Figures A-1 to A-7). This latter technique represents the situation when a person faces a plane mirror (Figure 4b). The images observed in the plane mirror by an observer facing it preserve their arrangement in the direction parallel to the mirror surface (objects that were on the left in the real world remain on the left when seen in the mirror), but the plane mirror reverses the order of elements in the direction perpendicular to the mirror surface causing the *left hand* appear as the *right hand* and vice versa. The image of the person observed in the plane mirror is therefore not that of a real person (e.g. the heart of the image person is closer to his right hand).

The question of why Giotto chose this method cannot be answered drawing solely on physics, however. The analysis requires physics as well as theology.

We cannot ask Giotto himself, and to the best of our knowledge no documents remain to testify as to his thinking in this regard. However, we can speculate by referring to the philosophy of St. Francis. He regarded the world as a *mirror* image of the Lord. The metaphors ‘‘the double life of St. Francis and Jesus Christ’’, ‘‘the mirror of perfection’’ and ‘‘mirror of the Lord’’ are common in traditional descriptions of St. Francis. The receiving of stigmata, at the culmination of his life, is described using this image:

> As Francis uttered a mighty shout of joy and pain, the fiery image impressed itself into his body, as into a *mirrored reflection of itself*, with all its love, its beauty, and its grief. (Chapin 1957)[4] (our italics)

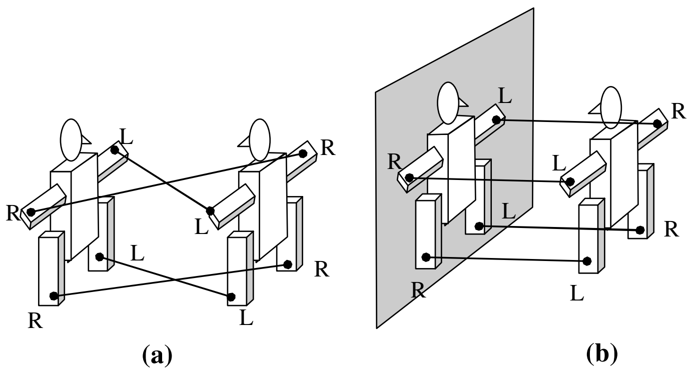

Figure 4. The joining of corresponding points (a) when two persons face each other, (b) when a person stands in front of a mirror.

Thus we can suggest that Giotto wanted to introduce the mirror idea into his picture. In fact, Giotto started a long tradition. His mirror-image method in tracing stigmata was followed by Gaddi at the end of the 13th century in Assisi and from there it spread to other medieval artists in Europe (Table I, Appendix 1). However, we also find examples of mixed correspondence involving only hands (e.g. Veneziano, Table I), or only feet (e.g. Lorenzetti, Table I). Table I in Appendix 1 shows that, with time, the mirror-image interpretation of the event declined and artists changed to the method of Figure 4a, i.e. of depicting two persons facing each other. Others avoided joining stigmata altogether. Was this because of the complexity of the choice they faced? All we know is that in modern paintings which portray the same event, mirror correspondence in joining of stigmata does not appear: the lines cross.

It is of interest to consider the fresco of stigmatization by Giotto in the Bardi Chapel in Florence (Figure A-2), one of three paintings on the subject produced by Giotto himself. In it we observe stigmata traced without left-right conversion. Is this evidence of Giotto's inconsistency? Perhaps not. The fresco in the Bardi chapel was later covered by another one. The final restoration, in 1840, followed contemporary methodology. The other two stigmata paintings of Giotto (the fresco in Assisi and the panel in the Louvre), which remained untouched, represent the master's approach.

The history of the portrayal of the stigmatization of St. Catherine of Siena shows a similar pattern. The event itself occurred in the 14th century and the saint was canonized in the 15th century, Manetti painted the scene in 1630 for the Dominicans (Figure A-3). Despite the much later date, the stigmata of St. Catherine were joined using the mirror-image interpretation. It is possible that the idea of the saint as a mirror-image of the Lord was adopted by Manetti as a renewal of the canon for the interpretive depicting of stigmatization established by Giotto, even if not all artists followed this canon.

3.2. THE ANNUNCIATION

The event of the Annunciation is of central importance in Christianity. It denotes the arrival of a message to Mary about the miraculous birth of her son. Canonized texts did not specify details of the event; these were left to the artistic imagination. Some artists did not show anything physical at all moving to Mary through space (e.g. Leonardo da Vinci showed only words flowing towards Mary). Others, however, showed an image traveling towards Mary. A survey reveals two types of artistic representation (Figure 5). In one, the image (a dove, a child or both) moves as part of a solid beam of light (Fig 5a). In the other, light is shown as a set of rays

Table I. Left–right correspondence at the representation of stigmatization of St. Francis

Artist	Year of production and art piece location	Hands connection	Feet connection
Giotto	1290, Upper Basilica, Assisi	II*	II
Giotto	1300, Louvre Museum, Paris	II	II
Giotto	After 1317, Bardi Chapel, Florence (restored in 1840)	X**	X
Taddeo Gaddi (Giotto workshop)	1300, Fick Museum, Cambridge, MA	II	II
Paolo Veneziano	1350, Gallerie dell'Accademia, Venice	II	One point
Gentile da Fabriano	1400, Brera Gallerie, Milan	II	II
Pietro Lorenzetti	1315–1330, Lower Basilica, Assisi	X	II
Florentine school (1)	1425, The National Gallery of Scotland, Edinburgh	X	II
Domenico Veneziano	1445, National Gallery of Art, Washington	II	X
Carlo Crivelli	1476, National Gallery of Art, London	II	One point
Le Louchier's Book of Hours (manuscript)	1450, Syracuse University Library	II	II
Lucas Van Leyden	1529, Rijksmuseum, Amsterdam	II	II
Nemet Ismeretien Mester	http://www.fvr.hu/galeria/ferenc/stig04k.jpg	X	II
Florentine school (2)	1475, The National Gallery of Scotland, Edinburgh	X	X
Bartolomeo della Gatta	1486, Church of St. Angelo, Castiglion Fiorentino	X	X
Albrecht Durrer	1505, Fine Art Museum, San Francisco	X	One point
Master of the Lindau Lamentation	1450, Wallraf Richartz Museum, Cologne	X	X
Master of Maiolica in Deruta	1530–1550, The National Gallery of Scotland, Edinburgh	X	X
Holy card	Contemporary card, Franciscan website	X	X

*II indicates connection between right and left corresponding to the situation when a person faces a plane mirror.
**X stands for the type of connection between right and left (hands and feet) corresponding to the real life situation of two persons facing each other.

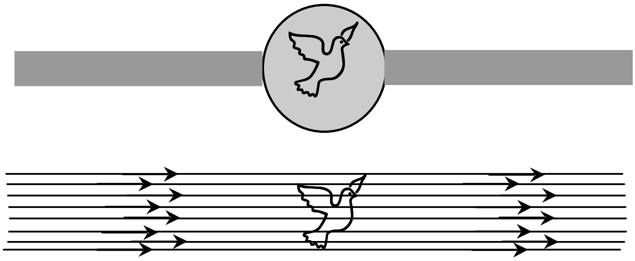

Figure 5. Symbolic representation of the two ways of depicting an image traveling through space: (a) The image travels as a part of a beam of light; (b) The image travels on a set of light rays.

(Figure 5b) on which the image is moving, as on rails. Why have some artists chosen the first mode of representation while others adopted the second?

In fact the mechanism of image transfer is a part of the theory of light and vision, which has a history older than many other branches of natural science (Cohen & Drabkin 1966). Several competing theories of vision were developed in Classical Greece. A major debate took place between the proponents of intro- and extramission theories. The Pythagoreans suggested the extramission theory of vision according to which "internal fire" leaves the observer and travels towards the objects seen (extended sense). The Atomists suggested the intromission theory and insisted on an eidolon (image), a replica of the object seen, traveling through space towards and into the human eye. Both theories developed in parallel and their apologists were in continuous dialogue with one another until, in the golden age of Arabic science, Al-Hazen (965–1039) arrived at his own understanding of vision, while using several Greek ideas (Lindberg 1976). In his view, light, being comprised of light rays, was reflected from all points on the surface of an object, and traveled in all directions. An optical image was created when the relevant light rays penetrated into the eye of the observer and reached the surface of the eye lens. Each point of the image was created by a single light ray from the object. Al-Hazen's theory became known in Europe through Arabic translations into Latin in the 12th and 13th centuries (Crombie 1959). Roger Bacon in Oxford (1214–1292) was among the first in the West to accept the new ideas, in the second half of the 13th century. The new theory appeared subsequently in the optics manuscripts of Witello and Pecham and circulated in Western Europe. Since then, and until Kepler's work in 1604, the understanding of light and optical imagery within the framework of Al-Hazen's theory (the light rays paradigm) prevailed among people educated in the Latin language.

Returning to the methods of depicting image transfer in paintings of the Annunciation, we can identify the two mentioned forms of representation of this event as reflecting two models of image transfer developed within the mentioned intromission theories of vision. The first and older model is the ‘‘holistic model’’ (Figure 5a). It corresponds to the Atomists’ eidola theory. The other model is the ‘‘point-to-point-by-one-ray model’’ (Figure 5b), corresponding to Al-Hazen’s theory. In Appendix we bring examples of both presentations.

It is relevant that the holistic mode of presentation belongs to the canon of Orthodox Church iconography in Eastern Europe (Figure A-4), while the presentation of images transferred by a bundle of individual rays, point by point, was favored by artists living in Western Europe, the realm of the Catholic Church (Figures A-5 and A-6). These separate traditions of presentation reflect the way in which optical theory spread, different cultural traditions being associated with different parts of the world. Indeed, the holistic theory produced by Greek classical science prevailed in the Greek canon of iconography, while the idea of individual rays transferring of an image, the optical idea of Al-Hazen, was in vogue in Western Europe where Latin manuscripts of optics written by Witello, Pecham, and Roger Bacon circulated in the later middle ages (Crombie 1959).

3.3. THE GORGON MEDUSA

Our last example involves Greek mythology. In the underground water cistern constructed in the sixth century by the Byzantine Emperor Justinian I in Constantinople,[5] two columns rest on huge sculptures of heads of the mythological Gorgon Medusa. The strange feature of both sculptures is their orientation: one is upside-down and the other lies on its side (Figure A-7). In both cases the face of Medusa is just above the surface of the water. Why this strange arrangement?

The reason guiding the Byzantine builders could be found in the fact that Greek mythology ascribed to Medusa the power to turn into stone any observer who dared to look at her. To overcome this obstacle, Perseus, a legendary Greek hero, was equipped by the goddess Athena with a mirror shield so that he could look at Medusa’s image while he approached and attacked her. By this means he succeeded in beheading Medusa. But even the dead Medusa’s head retained its lethal character (it was used by Perseus in later adventures). The legendary ban on looking directly at Medusa could have been in mind of the builders of the cistern in Constantinople. By arranging the heads, one upside down and the other on its side, both touching the water surface, the architect intended to remind the observer of the story and to offer him/her a safe way of looking at the Gorgon’s face, i.e. indirectly through its reflection (Figure 6). At the same time, the inverted image was already oriented to provide convenient observation.

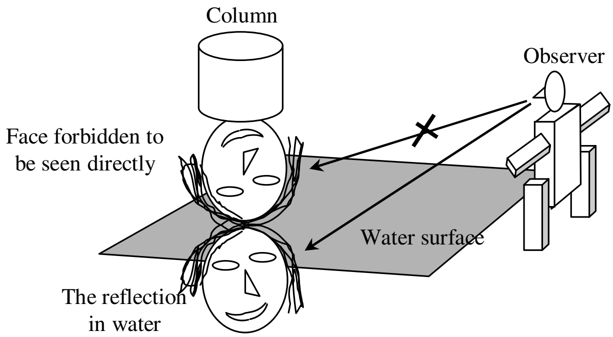

Figure 6. The upside-down arrangement of the sculpture of the head of the Gorgon Medusa allows the observer to look at the mirror image in the water surface and not directly at the face.

4. Relevance to the Learning of Optics

Scientific knowledge presents an accumulative product of thousand years of exploration. Although human, it cannot reside in a single individual and for a long time. Knowledge must be transferred and every person starts from ignorance. In the course of learning a person constructs his/her knowledge and this process is essentially different from loading data into a computer. People acquire knowledge through a long and gradual process of learning from a variety of resources and experiences. This represents a process of enculturation of the learner both in the humanities and the sciences.

In science education generally it has long been recognized that the way in which individuals mature with respect to scientific knowledge might resemble the way in which scientific knowledge has developed historically. The conceptions, discoveries and ideas (as well as mistakes, misconceptions and confusion) are sometimes remarkably similar. This is the phenomenon of recapitulation (first introduced regarding the development of the human embryo[6]) and later adopted as historicodevelopmental approach in genetic epistemology (Piaget 1970)[7]. The parallel cannot be exact, because the experience of an individual learning cannot replicate the way in which knowledge accumulated over thousands of years. Also, learning and cultural ecologies are vastly different, for both different persons and different periods in time. However, the patterns of knowledge growth, especially at the beginning of learning science, do include questions and conceptions similar to those in the past (e.g. Piaget 1974; McCloskey 1983; McCloskey & Kargon 1988; Wiser 1988; Galili & Hazan 2000b). This seemingly reflects the fundamental similarities between the sense perceptions and the thinking patterns of making sense (“mind machine”) of people living today and of those who lived in the distant past. Their experiences, observations and common sense were similar, and so the logico-mathematical and physical rules of making inferences in knowledge construction show a certain resemblance (Langer 1988).

Within this perspective and given that students actively construct knowledge during learning, the history of science becomes relevant to contemporary science education, and its use may reinforce the strategies of science instruction such as: "disequilibria" (Piaget 1985), "cognitive conflict" (Dreyfus et al. 1990), "conceptual change" (Hewson et al. 1998), "cognitive resonance" (Niedderer & Goldberg 1996, Galili & Hazan 2001a), etc. We have presented here three examples which, if used in the teaching of optics in any of these formats, might be of special interest to students because the context integrates physics, art and the humanities. Before generalizing, we will discuss the educational relevance of each of these examples.

Our discussions regarding the portrayal of stigmatization and the arrangements of the sculptures of Medusa involve an understanding of the relation between an object and its mirror image. Several studies have revealed that students have difficulties and strong misconceptions regarding the effect of a plane mirror (e.g. Bendall et al. 1993; Ronen & Eylon 1993), and educators have discussed ways of overcoming learning difficulties in this field (e.g. Galili et al. 1991; Galili & Goldberg 1993; Galili & Hazan 2000b).

Among other misconceptions, there is a common belief among students that a mirror inverts a picture from left to right whereas, in fact, the effect of the plane mirror is to change left-handedness to right-handedness, i.e. to change chirality (e.g. the clockwise thread of a screw is seen as anti-clockwise). The fascinating phenomenon of inversion by the plane mirror was recognized for thousands of years, and it has always been a subject of intrigue. In fact, symmetry change caused by a plane mirror is directly related to the topic of symmetry conservation by elementary particles – the so-called parity law or CP-conservation (e.g. Allonso & Finn 1968). Yang and Lee were awarded the Nobel Prize in physics in 1957 for the discovery of symmetry breaking in "mirror-reflected" processes. Today we realize that if the DNA molecule was to spiral in the opposite way (as in its mirror reflection!) it could not support life. Teaching these topics helps students understand what a mirror "does" to the image and what it "does not".

One way to construct genuine knowledge in this challenging area is to consider it within an interesting and intellectually demanding context. Such a context is suggested by the artistic representations of stigmatization and of the Gorgon Medusa. In particular, questioning the rationale of the artist (Giotto) in connecting hands and feet in an "inverted" manner can lead the teacher, if not the students, to more general questions such as "what does a mirror do to the image it creates?", "does the image really exist?", "where is the image located?", and so on. Such questions can stimulate the construction of genuine knowledge of the subject (Galili & Hazan 2000b), and naturally emerge if the teacher guides observation and discussion of Giotto's masterpiece. Such an approach, in itself will surprise students in a physics class and, therefore, be pedagogically effective.

A similar effect might be produced by a consideration of the strange positions of the sculptures of Medusa. This would include the intriguing story from Greek mythology. Discussion of the way in which a plane mirror causes inversion of the image, with reference to the myth (the decapitation of Medusa) and to the position of the Medusa sculptures in Istanbul can be used to disturb, if not remove, the misconception of right-left activity by the part of the mirror. The story of Meduza is simultaneously amusing and educative.

Our second example was related to image transfer in artistic representations of the Annunciation. The creation of an optical image is of central importance in optics curricula. Research in physics education has identified a wide variety of alternative conceptions which students construct regarding image transfer, either independently or by misinterpreting teachers' descriptions. Students' knowledge of optics can be represented by schemes of knowledge which manifest themselves in different situations (mirror, lens, pin-hole etc.) (Galili & Hazan 2000a). Two such schemes regarding optical image (both misconceptions) have been identified. In the Holistic Scheme the image is regarded as having traveled from the object to the observer or a mirror. Students often describe the image as bouncing ("reflecting") off the mirror or even as created by it (Bendall et al. 1993). The optical image is then regarded as a material object. This scheme of reification (a misconception), developed independently by students, represents an ontological replacement of the optical image (presenting an illumination pattern) so that the image is regarded as a material object. This account for an image is similar to the theory of optical eidola of the Atomists in Greek science (Galili & Hazan 2000b).

Another pattern of alternative knowledge is the Image Projection Scheme (Galili et al. 1993; Gallili & Hazan 2001b). Although erroneous, it presents an intuitively plausible idea. It regards the image as being produced by rays traveling from each point on the surface of the object directly to the eye of the observer, as if transferring the object image point-by-point. This scheme matches Al-Hazen's theory of vision, mentioned above. The problem of students' producing it could be remedied by discussing Al-Hazen's theory, thus bringing to the class a critique of this account of image transfer.[8] Instead of ignoring Al-Hazen's theory as being obsolete, such a discussion regarding image transfer could start from observation of the artistic representation of the Annunciation by various artists such as Van Eyck and Fra Angelico (Gallili & Hazan 2004). This would provide an aesthetically attractive context for effective instruction using the method of contrast, viz. comparing the classical Greek and medieval understanding with image creation as it is understood in contemporary physics.

5. Implications for Science Education and Concluding Remark

We are about to close the logical loop of this paper. Many paths of human intellectual activity bring an individual from observations of nature to an understanding of it. The currently prevailing pattern of education suggests to students two clearly separated trajectories as appropriate for two contrasting disciplines, the natural science and humanities. This dichotomy, characterized by Snow (1961) as "The Two Cultures", states their incompatibility on the fundamental level: rational thought versus emotion. At best, in this perspective, the gap can be bridged by mutual respect on the part of those involved. In fact, however, such an approach could be highly misleading in an educational context. Focusing on the formalism of the exact sciences, the "two cultures" approach overlooks that a philosophical, aesthetical and spiritual comprehension of the world has served as a major inspiration for construction of scientific comprehension throughout history. Feelings and beliefs are integral to science and, similarly, scientific ideas have penetrated into the humanities and arts, enriching them and sometimes creating their meaning. A cultural symbiosis created in this way (which, by definition, implies a relationship on the functional level, making two areas mutually dependent) could be presented in science education and attract the natural curiosity of many students.

In order to find an intellectual balance in education one may use the context hitherto seldom addressed in the same class: the artistic masterpieces which combine aspects of sensory pleasure with scientific rationale and humanistic ideas. Our examples suggest how using such works may reveal aspects of knowledge important for both art (to grasp certain meaning) and the sciences (to represent certain conception). This implies that the semiotic triangles for art and science (Figures 2 and 3), representing these two trends of intellectual activity as separated realms, although useful in order to emphasize the objective–subjective dichotomy in the nature of knowledge, might miss just the dialectic synthesis of both. In reality, science and the humanities are interwoven, being immersed into culture. This aspect is especially relevant for presentation in introductory science courses which address a wide audience of students.

By constructing science curricula involving aspects of art and humanities in a relevant context, one changes the agenda of learning from pure science (usually the perspective of its practitioners) to science enriched with the cultural content. Such curricula will adopt the features of the contemporary culture – multiple perspectives and meanings, validity (even necessity) of conceptual understanding – which are particularly relevant at the beginning of science education. If this were to be done, more students could become interested in science, including ones who do not intend to become professional scientists.

Finally, we note that unlike the later stage of education, specializing in providing professional disciplinary knowledge (college–university level), school, and especially high school, education should be, in our view, more oriented to establishing of scientific literacy of individuals, regardless their future choice of professional carrier. Such a curriculum seeks enlightenment for the future citizens. Culture signifies broadness of educational context, opposing the often-adopted curriculum focusing on the disciplinary formalism and problem solving procedures. Culturally enriched science courses fit the interests of much wider student population than that currently taking science in high school[9].

Appendix. Illustrative Pictures

Figure A-1. Giotto's Stigmatization of St. Francis in Assisi (1290). We emphasized the original lines drawn by the artist. The connection between hands and feet is as in the case of facing a mirror.

Figure A-2. Giotto's Stigmatization of St. Francis in Bardi Chapel, Santa Croce, Florence (1317). We emphasized the original lines drawn by the artist. The connection between hands and feet is as in the case of two persons facing each other.

Figure A-3. Stigmatization of St. Catherine of Siena by Manetti (1630). We emphasized the original lines drawn by the artist. The connection between hands and feet is as in the case of facing a mirror.

Figure A-4. The Annunciation in accord with the cannon of the Orthodox Church iconography. The image (emphasized) is moved to Mary with the non-structured flux of light.

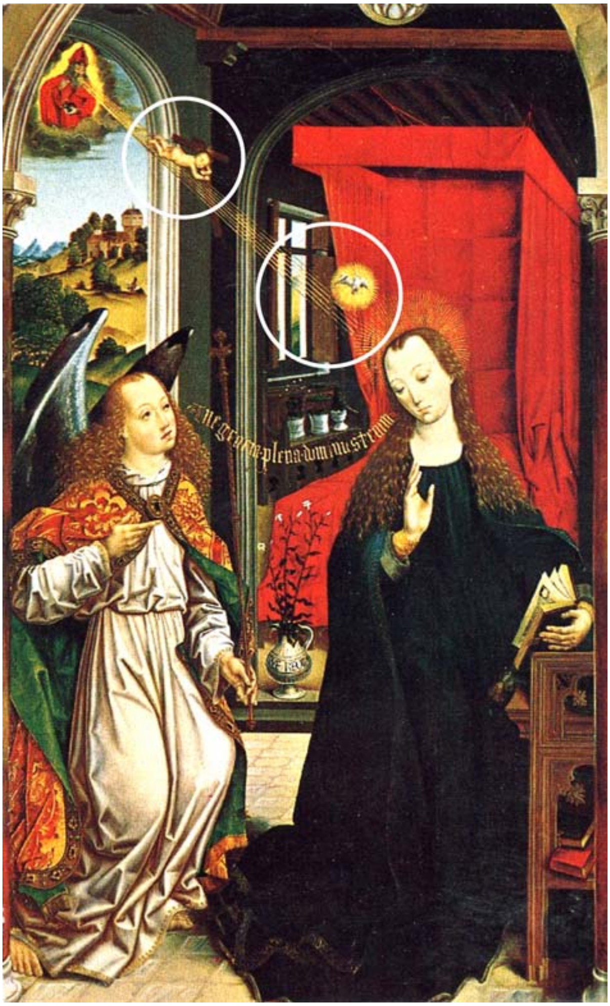

Figure A-5. The Annunciation by the Master of Retable of the Reyes Catholicos, 15 c. The images of the child and dove (emphasized) move to Mary with light rays. Message by words is also shown.

Figure A-6. Annunciation by Fra Angelico, 1452. The image of dove (emphasized) moves to Mary by a group of light rays in accord with the current understanding of vision.

Figure A-7. Two column bases in the underground cistern in Istanbul.

Notes

[1] It was suggested to expand this account so as to include the relationship between cultural phenomena, when one such phenomenon explains, conceptualizes and provides guidance in understanding of the others (Tseitlin and Galili 2006).
[2] The abundance of styles in painting, sculpture, architecture resembles the variety of sciences in general and of disciplines within physics, in particular, each with its own view of nature.
[3] We mean the crossing as it would be seen by an observer from *above* the persons, and not as it might seem to an observer fro aside.
[4] Quoting St. Bonaventure, the Catholic Encyclopedia describes St. Francis as follows: "He was in the eyes of all a *mirror* of holiness..." and "he made use of all creatures, as of so many *mirrors*, in which he viewed the Supreme Reason..."
[5] Now Erebatan Saray in the center of Istanbul.
[6] The idea that ontogeny recapitulates phylogeny was formulated in 1866 by Ernst Haeckel, German biologist, as a biogenetic law.
[7] Piaget's perspective of genetic epistemology identified a parallelism between the development of organization of collective logical and rational knowledge in human society, on the one hand, and the process of psychological formation of individual knowledge, on the other. Piaget analyzed the evolutionary process throughout the history of physics and mathematics and compared it with the growth of ideas in the development of the individual child.
[8] Some educators would call this treatment "cognitive conflict", we would prefer to identify the process as a "cognitive resonance". This terminology, however, does not change the nature of the treatment: presenting the learner with content which is inconsistent with his/her own belief.
[9] For example, currently, less than 10% of students chose to learn physics in Israeli high school, which is far away from the expectation of the modern society, fundamentally based on science and technology.

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