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ARTICLE

Discovering Socio-cultural Aspects of Science Through Artworks

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Abstract Scientific literacy is one of the primary purposes of science education which briefly focuses on using and interpreting scientific explanations, understanding science within its culture. However, science curricula emphasize science with its cognitive aspects and underestimate affective and aesthetic aspects of science. Science education needs to cover beauty of science for students to cross borders between their own culture and culture of science and to achieve the aim of scientific literacy. Relating aesthetic aspects of science with content of science and paving the way for aesthetic experiences through artworks may enrich science education. The purposes of this study are to discuss the need of integrating aesthetic aspects of science in science instruction and to propose examples and pedagogical suggestions to promote aesthetic experiences into the science education. Artworks are selected to present socio-cultural aspects of science to demonstrate the culture of science, their stories are explained, and pedagogical suggestions are proposed. Advantages and difficulties of using artworks in science instruction are discussed as a result of the study.

1 Introduction

What is the purpose of science education? In addressing this important question, national standards and instructional materials typically rely on the concept of "scientific literacy" as a core point (Sadler and Zeidler 2009). Science education within the framework of scientific literacy aims to achieve the following objectives: (1) to enable students to understand science as a cultural force, (2) to help them understand that science and technology are interrelated, (3) to make them technologically literate, (4) to help them utilize science in making sense of everyday occurrences, (5) to encourage them to consider science as a way to understand the

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natural world, and (6) to encourage them to employ scientific concepts and skills in their decision-making processes (DeBoer 2000). For science education to be considered successful, the required skills are defined as follows: to know, to use, and to interpret scientific explanations; to produce and interpret scientific evidence-based explanations; to understand nature and the development of scientific knowledge; and to be able to actively participate in scientific applications and discussions (National Research Council, NRC 2012). The main purposes of physics education are also based on scientific literacy. Physics education is identified not only as a discipline of teaching with the aim of nurturing scientists, but also as an activity to determine the social and technological aspects of science for future citizens in a technologically developing society (Lijnse et al. 1990).

A recent definition of scientific literacy relies on three competencies: the ability to explain phenomena scientifically and the skills to scientifically evaluate and design scientific enquiry as well as interpret data and evidence, which are assessed based on such contexts as health, natural resources, environment, hazards, and the frontiers of science and technology in personal, national, and global settings (OECD 2013). The 21st Century Science Project of England also defines a scientific literate person as one who can use the scientific perspective in thinking, discussing, and making decisions concerning individual and social purposes (Roberts 2011).

The need to forge cultural and social links to science education is apparent based on previous definitions. In relation to this, Aikenhead (1996) depicted science as a culture in which students have to interact in science courses, thus making science education akin to developing cross-cultural understanding. Accordingly, in science education, the aim should be to enable students to understand their own culture and the culture of science as well as to help them discover and explore the socio-cultural aspects of science.

In consideration of the principles of scientific literacy and the role of socio-cultural or cross-cultural understanding in science education, Lemke (2001) questioned the reasons why the aesthetic and emotional aspects of science are often ignored in science education, and why the rationalistic view of science is deemed appropriate for all students. According to Lemke (2001), science education should consider ideas more than mere concepts, because concepts are just abstract tools, whereas ideas have not only cognitive, but also behavioral and affective dimensions.

Similar to Lemke, Donnelly (2004) argued for an education for free human beings and, in accordance with this purpose, proposed a humanistic approach in curriculum design—one that appeals to the development of the autonomous self, the indeterminacy and meaningfulness of each subject matter, and the need to meet the challenges of relativism. A humanistic approach includes empathy, appreciation, and imagination (Jarrett 1973 cited in Donnelly 2004). Moreover, a humanistic science curriculum must include the human and social dimensions of scientific practices, values, and human concerns (Aikenhead 2003), all of which have been placed by science education on the back burner by focusing on content knowledge.

Overemphasizing content knowledge is parallel with the concept- or subject-centered curricula, which have a rationalistic view of excellence instead of focusing on the affective aspects of education. Although subject-centered curricula are easy to implement, to move through and test with their well-organized structure, they fall short in meeting students' interests and the needs of upholding contemporary life and motivating students to hone their thinking skills (Henson 2015). However, twenty-first century education needs problem- and society-based curricula that aim at developing students who can actively process information. Such curricula should promote democratic and social principles so that students can help improve and reconstruct society in the future. Therefore, science education should concentrate on problems in interdisciplinary contexts, such as those dealing with humans and society. As future citizens, students should develop values to understand and meet the upcoming needs and demands of society, rather than strive to acquire stable and rigid values. In keeping with the needs of contemporary education, the integration of humanistic and aesthetic contents into the curricula is important because aesthetics enable students to express their feelings better (Ornstein and Hunkins 2009).

As highlighted by scientific literacy, humanistic education also demands science education to teach students to use scientific knowledge for problem-solving and decision-making activities based on their own knowledge, thereby encouraging involvement by connecting oneself to the content (Hadzigeorgiou 2005). Parallel with the "How effectively can you use your learning?" question of scientific literacy (Aikenhead et al. 2011), humanistic science education asks, "Why should we learn/why do we want to learn something?" Such pragmatic use of scientific knowledge covers the moral, ethical, and aesthetic aspects of science that centralize values (Hadzigeorgiou 2005). Norms and values are essential for learning science as they constitute a socialization content; provide a strong background for ethical, social, cultural, and political reasoning; and enable students to compare and contrast daily life experiences and scientific phenomena (Östman and Almqvist 2011).

In a *humanistic twist*, the history of science has been presented as a tool for science education, because it presents the interaction between science and society and helps students appreciate the interaction among people within this context (Wang and Marsh 2002). Various examples from history of science have shown how scientific discoveries significantly affected human opinions pertaining to politics, environment, healthcare, and economics; how authorities and scientific societies influenced how science works; and how technology developed as a result of ongoing scientific endeavors (Seker 2012). Such examples that illuminate the interaction between science and society can help students to value their own learning and understand science within the special contexts of their cultures and values.

Galili and Zinn (2007) also highlighted the importance of beliefs, emotions, and values in science education, and showed that scientific ideas, humanities, and art are actually nested in and enrich one another. As science and humanities are already embedded in one's culture, such an interaction among science, humanities, and art should enrich the teaching of science courses. Such a cultural symbiosis, which can be achieved by relating art and humanities with scientific content, may transform science education from teaching pure science to enriched science education. If this cultural symbiosis is actualized, then the interests of students—including non-science students—in science can increase (Galili and Zinn 2007).

The current study is built on two key ideas. First, science is a culture in itself. Second, science education should help students become more familiar with this culture so that they can imbibe values about science and its socio-cultural interaction. Therefore, a humanistic and aesthetic approach must be developed to enable students to focus on the socio-cultural aspects of science as well as develop self-expressions and values concerning social problems.

2 Aim of the Study

The purpose of this article is to discuss the need to integrate aesthetic aspects into science education and the literature on aesthetics, aesthetic experience/understanding, art-centered experiences, and art and curriculum integration to achieve the aim of scientific literacy and help students cross socio-cultural borders. Samples of art-centered experiences are proposed in this article to help achieve the goal. In light of the related literature, science is addressed as a culture within the context of scientific literacy. Due to its rich context and content in presenting the socio-cultural and ethical aspects of science, the history of science is taken as a tool to combine the aesthetic and cognitive dimensions of science, after which the socio-cultural structure of science is presented based on the history of science. The representative artworks that demonstrate this combination are presented to enable students to have art-centered aesthetic experiences. The artworks are specifically selected to represent the socio-cultural interactivity of science within the context of the history of science. Selected artworks are described, and suggestions are presented to teachers to help them encourage their students to utilize artworks and achieve aesthetic experiences.

3 Aesthetic Understanding/Experience

The German philosopher Baumgarten first introduced the term "aesthetics," which was defined then as the "science of perception." Although he did not separate aesthetics from cognition, he set the levels of aesthetics below the cognitive skills that can be perceived by our senses (Davey 2002, pp.162-163). Dewey defined aesthetics as the experience of perceiving and enjoying, stating that for something to be recognized as aesthetic requires the support of human values (Dewey 1934, pp. 3–34).

From the Deweyan aesthetics view, learning is a combination of cognition, action, and emotion (Girod et al. 2003). Founded upon Dewey's ideas, Girod and Wong (2002) proposed three key properties of aesthetic experiences: they are compelling, transformative, and unifying. An aesthetic experience is compelling because aesthetic understanding compels us to learn more and not to merely reach a goal. Through an aesthetic experience, students think about ideas, and their desire to talk about these ideas and use them in various situations. In this context, an aesthetic experience is unifying when a student realizes that the previously separate elements are, in fact, coherent. Students can better make sense of the world and make predictions as they see the relations among these separate elements. Meanwhile, an aesthetic experience is transformative when students state new ideas, beliefs, or goals of their own, which present the intrinsic value of learning (Girod and Wong 2002). As an outcome of the progress on these aspects of aesthetic understanding, concepts that form a body of knowledge are transformed to living ideas, and such a transformation provides rich experiences beyond the classroom walls (Girod et al. 2003). Ultimately, such a teaching approach stimulates students to see the world differently, and consequently, think and behave differently (Pugh and Girod 2007).

Supporting Dewey's ideas, Wickman (2006) suggested that science would cease without integrating aesthetics. This is because aesthetic understanding plays a crucial role in deciding which problem is scientifically interesting, in choosing which methods to employ in solving problems, and in continuing with the research process, simply because they are all related to the personal values held by scientists who are making such decisions. Values are a crucial point in learning science because they are related to judgments on what counts as (in)valid knowledge and those that are related to other people and nature (Östman and Almqvist 2011), which are highlighted in scientific literacy. Similarly, Flannery (1991) emphasized that aesthetic aspects, such as values that have an effect on scientific studies, the subjective aspects of science, and errors in science, should be integrated into science education so as to present science in all its richness. Hence, science instruction would be more interesting with the inclusion of the aesthetic dimension of science, although the process of acquiring and developing better attitudes as well as manifesting changes can take a long time.

Aesthetic experiences also play important roles in discovering the socio-cultural aspects of science by encouraging students to criticize social norms of the past and the present. In this way, students may develop values that will allow them to think and behave insightfully as future citizens, along with the possible transformative aspects of aesthetic experiences.

4 Art-Centered Aesthetic Experiences

The mere existence of art objects is not necessary in gaining aesthetic experiences—art only becomes aesthetic in relation with reason and enjoyment, because aesthetics refers to perception and enjoyment (Dewey 1934, pp. 10–11). In other words, art has the potential to facilitate aesthetic experiences by providing opportunities for both enjoyment and perception.

Art is sometimes defined as “auto-telos” (self-objective), a word which means something that has an objective of its own. The objective of art is to give pleasure or joy. In comparison, when listening to music, what leads us to do so is the pleasure that we feel in performing that act (Soykan 2015). Thus, on the one hand, art-centered experiences lead to enjoyment, which in turn, is a factor that increases the meaning and value of the experiences (Jackson 1998, p. 35).

Perception, on the other hand, involves establishing relations among the elements of the whole and between what is happening and what has been done in the past and present, and in the present and future. Art highlights the relations among these aspects because art involves selection. Specifically, artworks bring effective elements forward, ignore the irrelevant elements, and provide intense and compressed presentations of certain ideas (Dewey 1934, pp. 4–20). For an experience to be an art-centered experience, the perceiver should create an experience of his/her own by encountering and solving problems. Perceiving an object is not just a function of all five senses regardless of its past; rather, perceiving an object is to carry it from the past into the present to enhance the meaning of that object. Perceiving something is to understand the relations among its individual components; therefore, the effects and their results should be linked to perception. In this process, the perceiver remakes past experiences and creates new ones (Dewey 1934, pp. 4–20).

One who appreciates an artwork tends to spend time on it and finds the art object to be engaging, motivating, and even troubling or puzzling. As a result of this appreciation, that person’s former habits and perspectives on the world could begin to change (Jackson 1998, p.33). In this sense, art objects not only provide meaningful experiences, they also have the potential to change our perceptions of the world, redesign our habits by presenting new ways of thinking and perceiving, and add value and meaning to our future experiences (Dewey 1934, pp. 4–20).

Perception is not like recognition as it takes more time to develop. For Dewey, there is no final term in appreciating an artwork. Furthermore, art-centered experiences do not start or terminate with the existence of an art object, such that indirect perception could continue even when the direct perception is over. The responses that arise from one’s direct encounter with an artwork are continuous; hence, the effects of appreciating an artwork can still be revealed in one’s future experiences (Dewey 1934, pp. 20–34).

As part of the continuity aspect, art-centered experiences sum up and conserve meanings. In such experiences, when aesthetic perception is interrupted, there is no longer a need to revise previous levels of that experience. For example, you do not need to read a book from the very beginning or watch a movie from the first minute after taking a break. This is because in art-centered aesthetic experiences, things retained from the past continue to be nested in one's perception. Such structure of the aesthetic experience proceeds to understand what is coming (Dewey 1934, pp. 20–34). Hence, in terms of perception, aesthetic experiences link the past to the present and the present to the future.

In conclusion, art objects provide materials for aesthetic experiences, and facilitate the process of stimulating creativity, promoting learning, creating social and cultural meanings, and integrating different fields (Marshall 2005). Moreover, art can be taken as a booster element to enhance aesthetic experiences given that artworks have the potential to stimulate and change our perceptions as well as provide links from the past to the present and to the future, hence redesigning and enhancing the values of the individuals (Dewey 1934, pp. 4–34) as they create social and cultural meanings from what they are perceiving. On this basis, the integration of art-centered experiences in science instruction shall be discussed in the following sections.

5 Curriculum and Art-Centered Experiences

Davis (2008, p.7) believes that the value of art in education is clear. However, as mentioned earlier, science curricula place more emphasis on the cognitive and rational perspectives of science (Girod et al. 2010) and tend to underestimate the aesthetic aspects of science and related art-based experiences (Flannery 1991).

Eisner (2005) highlighted the importance of developing an academically, socially, and emotionally whole child as an aim of education by considering students' emotional, social, and intellectual responses. Given that art provides opportunities to use feelings in the process of thinking and making rational choices, art should be integrated to the curricula as a kind of pedagogical support (Eisner 2005). On this basis, Mueller (2006) supported the idea that the appealing part of science—or the "beauty of science"—should be emphasized. The so-called beauty of science (e.g., art) should be integrated into science education instead of the latter just focusing on the limited context of science.

According to Cross (2014), science curricula comprise three components, and the absence of one of them or the lack of balance among them would cause certain problems. These components, namely content knowledge, interest, and communication, can be used to support and enrich art-centered experiences. Science communication (i.e., students' ability to communicate their content knowledge) is an important factor in science education (Chan 2011). The importance of communication in scientific literacy has been highlighted by Krajcik and Sutherland (2010), who argued that students need to discuss, argue, and explain scientific evidence. Asking questions, explaining evidence, and proposing new ideas during classroom discussions complement the process of sharing knowledge (Rivard and Straw 2000). Dewey (1934, pp. 22–23) also added that art is the most effective, universal, and open form of communication. Art-based experiences advance students' skills in interpreting information and creating meaning as well as provide students with the opportunities to create their own worldviews by expressing themselves (Davis 1999). Interest, the second dimension of a science-based curriculum can also be supported by art objects, as they reach more students and make learning meaningful and enjoyable (Noblit et al. 2008, pp.155–156) and engage students in learning (Cawthon et al. 2011). Finally, for the last dimension of the curriculum, content knowledge as the focus of science education can be improved with art-centered experiences by stimulating interest among students and enabling them to better communicate scientific concepts (Davis 1999; Rivard and Straw 2000; Bradbury et al. 2013).

On the one hand, Galili (2013) encouraged the integration of art into the science curriculum, because artworks (or "pictorial images" as the author calls them) develop advanced abstract thinking, involve students emotionally, enrich their representation of concepts, and ultimately support the science curriculum. On the other hand, based on the frame of humanistic science education, as stated by Hadzigeorgiou (2005) in his study, art-centered experiences have the potential to encourage involvement among students. Such experiences facilitate active participation by creating links between the student and the object being conceptualized, thus helping students develop global awareness and understand social problems—possibly even contributing to solve them—by linking relations among the different elements of a whole. Moreover, the enjoyment aspect of art can help teachers plan pedagogical approaches within the frame of the "science-as-fun" context without underestimating the importance of the concept.

Studies on the integration of art into the curriculum of other academic disciplines have demonstrated the role of art in constructing and expanding knowledge (Hamblen 1997); in enhancing cognitive processes and people's perception of the world (Vanzant 2008); in encouraging creativity and imaginative abilities, inquiry skills (Efland 2002), and individual interest (Türkoguz and Yayla 2010); in stimulating wonder (Campbell 2004); and in promoting lifelong learning for non-science students (Flannery 1992). Therefore, the integration of arts into the science curricula by focusing on the socio-cultural aspects of science can promote the role of aesthetic experiences and the use of a humanistic approach in science education. This is because artworks have the potential to present socio-cultural settings and human aspects of science, to attract students' interest and increase their involvement in instruction, to encourage deeper classroom discussions on science, and to consequently develop social values as a result of the learning process.

6 Teachers' Role in Promoting Aesthetic Experiences

Art provides a wealth of examples that can actually help teachers present ideas; however, these examples are often not created for the purpose of instruction. Therefore, teachers play an important role in transforming artworks into appropriate educational tools (Galili 2013). Pugh and Girod (2007) argued that, within the frame of aesthetic understanding, the teachers' role is to transform concepts into living ideas. Hence, they proposed pedagogical ideas and classified them in two categories to promote this role as well as effectively introduce aesthetic experiences into science classes. The first category (1–3) consists of methods of crafting ideas out of concepts, whereas the second category (4–5) comprises methods of modeling and scaffolding transformative and aesthetic experiences. These ideas are the following from Pugh and Girod (2007), unless otherwise noted:

1. *Restore concepts to the experience in which their origins and significance are embedded.* The scientific concepts should be handled in their original forms and then "restored to the experiences in which they were first developed and debated as ideas" (p.14) to discuss why a concept is considered important, how science works, how knowledge is constructed, and how a concept can have an impact on science and the rest of the world.

2. *Foster anticipation and personal experience*. Anticipation is an important aspect of aesthetic experiences; hence, these teachers may select effective elements of the concepts and bring them together. Teachers should provide opportunities for students to explore and be enthusiastic about, ask questions to encourage their students to be more creative, as well as discuss and demonstrate how scientific ideas have the power to change one's perception of the world.
3. *Re-seeing the object to expand perception*. Art teaches students to perceive an object not just by looking at it but also by viewing it from different perspectives. Therefore, teachers should make it possible for students to use different perspectives in the process of perceiving. To achieve this, the teachers must train their students to look at the world with different eyes (i.e., "re-seeing") and to exert more effort to see minute, often overlooked details. Re-seeing also leads to new questions (e.g., "What's really going on here?" or "What kinds of things do I need to know more about to really re-see this?"), through which students can explore and learn further (Girod et al. 2003).
4. *Model a passion for the content*. This method refers to the ways of knowing about aesthetic understanding. Teachers should present content in a motivating way. If teachers do not develop students' passion for the subject, it would be difficult to motivate them to learn and re-see the world. Hence, as a leader, the teacher should understand how content enriches life, from which he/she can create a culture for aesthetic experiences.
5. *Scaffold students' action, perception, and valuing*. Teachers may use scaffolding techniques to facilitate a better aesthetic experience for their students.

The current study adopts the Deweyan aesthetics approach with transformative aesthetic experience and uses Pugh and Girod's (2007) pedagogical ideas for aesthetic experiences. Therefore, in Section 8 (i.e., Discovering the Socio-cultural Aspects of Science), selected artworks are presented within the framework of these ideas, to clarify and facilitate the teachers' role in promoting aesthetic experiences and empower them in the task of leading their students to discover and explore the socio-cultural aspects of science.

7 Related Studies on Arts and Physics

Several studies have focused on the interrelatedness of physics and art. In one of the most cited works in this field, Shlain (1991) presented breakthroughs in art and physics throughout history, and revealed astonishing similarities of vision. However, most of the studies connect physics and art in terms of optics concepts. For instance, Gilbert and Haeberli (2008) focused on such concepts as light, color, and photography, whereas Leibowitz (2008) dwelled on art-relevant subjects, such as lenses, color theory, and sound, to demonstrate the mutual characteristics of physics and art. Reeves (1997), meanwhile, focused on the effect of Galileo's studies on seventeenth century artists' works, specifically in the field of optics.

Considering the art and physics themes from the educational perspective, past studies have discussed the use of artworks in physics education. For example, Herklots (2004) argued that using art in physics instruction can enrich students' experiences, especially when the technique or context of a painting is related to the subject of the lesson. To exemplify this claim, Herklots presented the paintings of Salvador Dali, which were influenced by the atomic age. By discussing various examples, Herklots underlined the importance of visual art in providing possibilities of bringing the subject alive and connecting physics with other areas.

Similarly, Galili and Zinn (2007) discussed the role of artworks in students' understanding of some concepts of optics. Specifically, they presented their discussions in terms of artworks on left–right correspondence when a person faces a plane mirror. Galili and Zinn (2007) indicated that a cultural symbiosis, which can be created by connecting scientific ideas and art, can attract students' interest and curiosity. Moreover, they believed such culturally enriched courses are better than traditional science courses given the fact that the science curricula focus on creating scientifically literate and enlightened future citizens (Galili and Zinn 2007). In his latest study Galili (2013) used artworks in teaching the mirror effect concept and nature of science, and furthermore, artworks can trigger classroom discussions, which in turn, can uncover students' preconceptions, help make their abstract ideas more concrete, and facilitate better memorization of content. He further emphasized that the use of artworks in teaching abstract concepts in science instruction would make the discussions more engaging for many students.

The abovementioned studies that connect artworks and science instruction mostly made this connection on the concepts of optics, which students can discuss through images. Going beyond this, the present study looks at the use of artworks in teaching various scientific concepts, specifically physics concepts, to help students discover the socio-cultural aspects of science instead of only learning about the concepts.

8 Discovering the Socio-cultural Aspects of Science Through Artworks

Five samples of artworks were selected for this study, and each of them focuses on different aspects of the socio-cultural context of science. These samples are presented, and pedagogical suggestions for applications in actual classroom settings are also discussed.

The first sample is a fresco called *Galileo dimostra la legge di caduta dei gravi* (*Galileo demonstrates the law of falling bodies*) by Giuseppe Bezzuoli (Fig. 1). The fresco shows various aspects that are representative of that time, such as royalty, the church, and Aristotelian scientists, and focuses on the relationship among scientists, the scientific community, and scientific authority. With respect to the description by Museo Galileo (2006), at the center of this fresco, we can see an inclined plane, behind which Galileo (C in Fig. 1b)—a University of Pisa professor—stands and shows result of the experiments to his friend, the famous philosopher Jacopo Mazzoni. On Galileo's left, we can see a group of young students (D in Fig. 1b) assisting Galileo in the investigations. In front of the inclined plane, a Professor (B in Fig. 1b) rests on one knee as he measures the fall time with the pulse beats. The right side of the fresco features a group of scholars (A in Fig. 1b) searching the writings of Aristotle, looking for an explanation for the new fact. On the left side of the scene, a figure of royalty in the form of Don Giovanni de Medici (E in Fig. 1b) sits with a grim expression on his face. More importantly, as if they were meant to drive home the whole point, the Cathedral and Tower of Pisa were placed in the background to indicate the locations wherein the first discoveries in dynamics were made.

The fresco in Fig. 1 shows the interrelations among scientists and the scientific community. Throughout the fresco, the teacher can restore the concept to motion and specifically Galileo's inclined plane experiment, allowing students to "experience" the experiment. Inclined plane experiment is one of the experiments which was detailed in Galileo's book *Dialogues Concerning Two New Sciences*. By rolling balls down the particular distances of the inclined plane and measuring the time with pulse beats and a water clock, Galileo presented the ratio

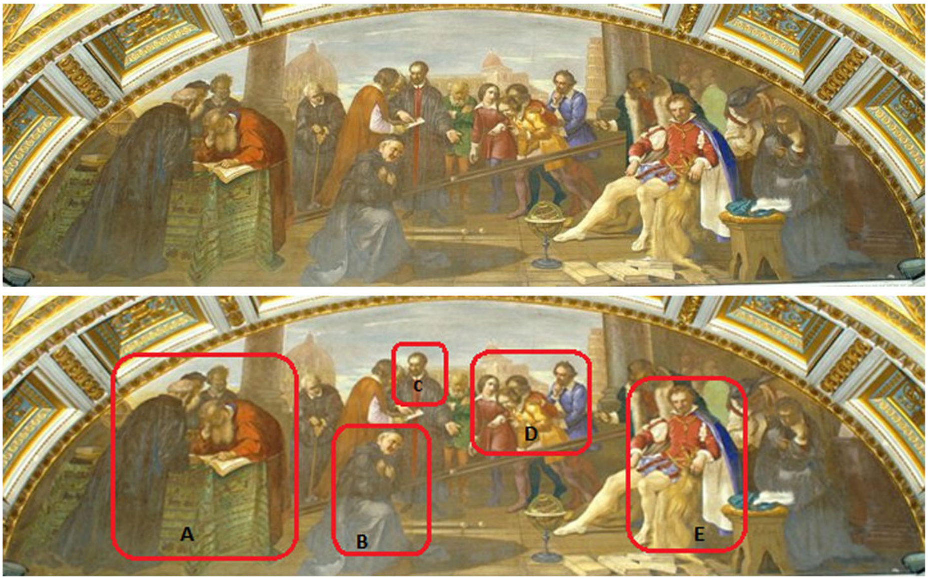

Fig. 1 **a** Galileo dimostra la legge di caduta dei gravi—Galileo demonstrates the law of falling bodies (1841) (With the permission of Museo di Storia Naturale Università di Firenze, Sez. di Zoologia "La Specola"—Italia. Photo credit: Saulo Bambi—Museo di Storia Naturale/Firenze). **b** Galileo dimostra la legge di caduta dei gravi—Galileo demonstrates the law of falling bodies (1841) in detail

between distance and time which is addressing the concept of acceleration (Galilei et al. 1914, pp.178–179). The teacher can utilize Galileo's own words from his book to construct the lesson around the history of the inclined plane and re-create the experiment. Pugh and Girod (2007) further emphasized the fact that the teacher must select the effective elements of the concepts and bring them together to foster anticipation and initiate the vital personal experiencing process. Indeed, the fresco brings together different elements of science and society. Questions depicting scientific ideas while also leading to further discussions may have an effect on changing students' perception of world; moreover, teachers can provide a medium that can increase students' enthusiasm in the lesson. As for re-seeing, the teacher can expand the perception scene of the fresco by directing students to examine it in pieces with accompanying questions, such as "Why are the boys next to Galileo excited?" and "What was the man doing in front of the inclined plane?"

Based on the fresco in Fig. 1, Aristotelians, Medici, as a figure of royalty, and Galileo with his colleagues and students can be discussed in the classroom to foster students' understanding of the social context of the discovery of acceleration. The interactions among Galileo, the royal family, and the church can be mentioned to stress the role of authorities on science and scientific endeavors. Students can then discuss what affects scientific endeavors either in promotive or disincentive ways during specific eras in history.

In addition, by measuring the time with pulse beats, just like the man in front of the inclined plane, students can be encouraged to discuss Galileo's methods and measurement instruments in the seventeenth century. Specifically, by referring to the fresco, students can also experience measuring time with pulse beats and discuss the measuring instruments, the SI unit system, and the sources of errors in an experiment. The teacher can then highlight the difference between qualitative measurement, which is based on interpretation, and quantitative measurement, which is based on numerical measures, as well as the need to come up with a unit system for accurate and precise measurements. As for the scene with the Aristotelians (A in Fig. 1b), it can be used to initiate a discussion on measurement systems as well as the evolution of different ideas in the history of science. Finally, the teacher can help students understand the tentative nature of science by stressing the ideas of Aristotle and Galileo regarding motion.

The second sample (Fig. 2) is *The Triumph of Science* by Nicolo Barabino. This painting was originally located on the ceiling of Palazzo Orsini in Genoa, Italy. Allegories of science and obscurantism were depicted in this painting, along with images of 39 scientists dominating the painting from left to right. As Barabino illustrates, Cuvier, Linneaus, Hippocrates, G. Vico, Montgolfier, Rosmini, Guttenberg, Swartz, Archimedes, Diogenes, Mosé, Machiavelli, Napoleon, Giustiniano, Leibniz, Mors, Clepper, Ershel, Volta, Galvani, Papin, Newton, Cavalieri, Caselli, Fulton, Descartes, Stephenson, Franklin, Watt, Degert, Leonardo, Lavater, Toricelli, Marco Polo, Colombo, Copernicus, Galileo, Lavoisier, and F. Gioaia take part in the triumph of science (ADSI 2009).

The painting mainly highlights the technological and scientific innovations resulting from the invention of the battery. A woman—representing science—is placed at the center of the painting, surrounded by white light, which represents the "light" of enlightenment. Surrounding the woman, a crowd of people can be found, including such scientists as Galileo, Newton, and other natural philosophers and technologists. A long meeting table can also be found next to the woman, again, surrounded by people. In front of the table, on the right side, Alessandro Volta is demonstrating his electric battery to the prominent scientists, technologists, and philosophers of his era and even of earlier times. Along with the battery, some other scientific instruments and technological innovations, such as the steam engine, are placed on the table. Another detail in the crowd, although depicted at the background, the painter included Napoleon Bonaparte as a symbol of authorities who mediate between the state and the ongoing endeavors of scientists and technologists (Pancaldi 2005).

This painting (Fig. 2) has various details that emphasize the interdependencies among science and technology and science and society, as well as the scientist-philosopher and

Fig. 2 *The Triumph of Science* (1876) (reprinted with the permission of Princeton University)

science-authority interactions. According to the methods proposed by Pugh and Girod (2007), the teacher can use this painting to relate concepts to the history of the invention of the battery. Students can reconstruct Volta's battery and discuss the process of invention. This painting also covers various details that the teacher can segregate into sections by selecting scenes related to the lesson's objectives. By using scenes from this artwork, the teacher can bring together the scientific community, authorities, technology, and science, and then emphasize how science works and how science can affect technological development. Details about science, the enlightenment era, and scientists and philosophers found in the crowd can also be used for activities to re-see the artwork to expand perception as Pugh and Girod (2007) suggested. By focusing on science as depicted in the body of a woman surrounded with light, the age of enlightenment—and how it came about—can be discussed in detail. Students can then be asked about the age of enlightenment and the accompanying scientific revolution in that era so that students can perceive and better understand the cultural background of scientific discoveries.

Moreover, by explaining that the people in the crowd include Galileo, Newton, philosophers, and technologists, the interactions between science and society can be stressed. Meanwhile, the inclusion of Alessandro Volta and Napoleon Bonaparte can be highlighted to demonstrate the role of authorities—like Napoleon Bonaparte the emperor of France—in promoting (or restricting) scientific endeavors. Scientific and technological instruments, particularly the battery, are also important images that can be used to demonstrate the interaction between science and technology. Concentrating on the figure of the battery, including the history of batteries and the invention of the Volta battery, and how it affected scientific studies can be discussed. Then, based on this perspective, the teacher can discuss how science affects technology and how technology affects science regardless of the era in which scientists lived.

The third sample (Fig. 3) is the frontispiece of the *Voltaire's Elements of the Philosophy of Newton*. This painting mainly depicts Voltaire, Newton, and Émilie du Châtelet, and focuses on the interdisciplinary relations between science and literature, along with the side topic of gender issues. In this frontispiece, a man, Voltaire, is seen on his desk. Hovering over Voltaire, we can see another man, Newton, wearing a white robe and also surrounded by light. The light symbolizes the light of truth, a divine light that is depicted as coming from Newton. The other figure in the painting is Émilie du Châtelet, a French woman in science, reflecting the light from Newton to Voltaire so that the light of knowledge shines on Voltaire. Books, a globe, and mathematical and scientific instruments surrounding the desk constitute the other elements of the painting (Porterfield 2005).

The frontispiece in Fig. 3 includes interesting and important details regarding science, literature, and gender issues. Voltaire was a writer/philosopher, Newton was a scientist, and Émilie du Châtelet was one of the first women in science in France. Voltaire is an important character in both literature and science. He is an important scientific figure, who also supported Newton with his book on the philosophy of Newton. For the aesthetic experience, the teacher can discuss the history of Newton's discoveries on optics or gravity because Voltaire's interest concerned these two concepts. Although this frontispiece is not solely meant for teaching about the concepts of optics or gravity, the teacher can present it at the end of the instruction by linking Voltaire's interest on these concepts and using it as a jump-off point from which to discuss the socio-cultural aspects of science. By bringing Newton, Voltaire, and Émilie du Châtelet together, the teacher can present how science and literature are related to each other. Meanwhile, for activities to re-see the artworks to expand perception, the teacher can use

Fig. 3 The frontispiece of Voltaire's *Elements of the Philosophy of Newton* (1738)

scientific instruments seen in the frontispiece and, by using leading questions, help the students see details, relate them to the topic, and employ different perspectives to perceive the whole.

Voltaire's efforts to promote and support Newton can also be mentioned, and based on such examples, the students can discuss the varied interrelations between science and literature. As an important detail, the inclusion of Émilie du Châtelet is an opportunity to discuss the role of women in science. Émilie du Châtelet, although more popularly known as Voltaire's lover, is a forgotten, self-educated woman in science, whose study on the nature of light was published by the French Academy of Science. Furthermore, she translated Newton's *Principia* and added her clarifying notes to help French scientists understand it better (APS Physics 2008). During the lesson, the teacher can mention her contributions to physics as well as discuss the role of women and their contributions to science. This may motivate non-participating female students to study science further.

The fourth sample (Fig. 4) is a frontispiece of Guérison de la paralysie par l'électricité (1772) by l'abbé Sans (Guédron 2009), by Jean-Baptiste Chevalier. It shows the effect of an important discovery on the public. Two men, one lying on a chair and another standing, are

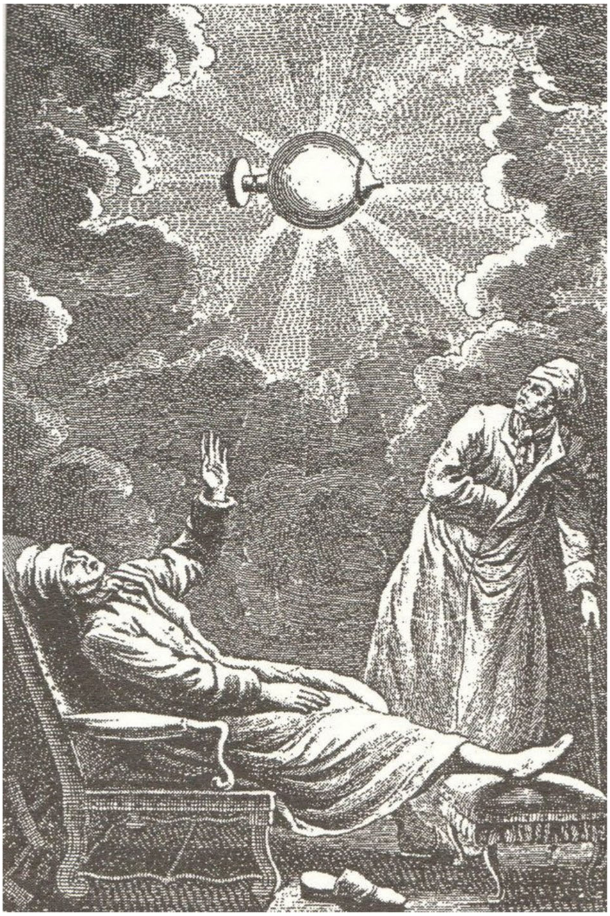

Fig. 4 The frontispiece of *Guérison de la paralysie par l'électricité* (1772)

shown in the artwork. A bright light can be seen surrounding an electrostatic generator on the upper zone of the artwork. The electrostatic generator is surrounded by light to demonstrate its power, because it is thought that electricity is the only hope for patients. Therefore, the man lying on the chair is a patient stretching out toward the light with the thought of "getting well" with electricity. The other man standing seems to be in doubt and looks up to the light (Tez 2008; Guédron 2009).

As demonstrated in Fig. 4, people in the eighteenth century believed that electricity had the power to cure the illnesses. Then, people used Volta's battery for several maladies, such as toothaches, earaches, and even blindness and deafness in the nineteenth century. Many people were hoping to be healthy with the power of electricity. Using this artwork, which demonstrates the effect of science on the people, the teacher can discuss the history of electrostatics and induce experiences with electrostatic generators. By using details on the effects of physics on health care, the teacher can foster anticipation and show the value of science. An activity to re-see the artwork to expand perception can be based on the facial gestures of the men (one is hopeful, whereas the other is doubtful). By using this artwork, students can discuss how scientific discoveries can affect people, especially in terms of the right or wrong use of new technology. Students can compare such examples with contemporary ones. Furthermore, nineteenth century studies on the effects of electricity on the brain can be mentioned, which were not accomplished because of the thickness of the skull prevented the electric current from reaching the brain. Additionally, for a discussion on the interdisciplinary nature of science, studies on the effect of electricity on human brain and nerves can be underlined, and their results in a specific field of medicine (i.e., electrophysiology) can be mentioned (Tez 2008).

The fifth sample (Fig. 5) is a fresco painted by Guiseppe Bertini (1858) called *Galileo Galilei che mostra l'utilizzo del cannocchiale al Doge di Venezia* (*Galileo Galilei showing the Doge of Venice how to use the telescope*). This artwork demonstrates the importance of scientific inventions at the beginning of the seventeenth century. In Bertini's fresco, a group of people, including the Doge of Venice, Galileo, and senators of Venice, are portrayed at the top floor of the bell tower of St Mark. Galileo, who is standing by the Doge in front of the group of senators, is holding the telescope on the table. Meanwhile, the Doge of Venice is wearing a robe that demonstrates his affluence and authority. The people standing backward are wearing red robes and white collars for the ceremony signifying the church and nobility (Mair 2012). Various facial expressions are depicted by the men standing behind the Doge and Galileo. A globe on the ground and a framed diagram leaning on the wall are also included in the fresco.

The fresco in Fig. 5 has enough details that can be used to discuss the effect of technology on science and its interaction with society. The teacher can discuss the history of the invention of the telescope. With the aim of fostering anticipation, he/she can address the characters in the painting, such as Galileo, the Doge, and the Venetian senators, as well as the scientific instruments, such as the telescope and globe. In using these elements, the teacher can focus

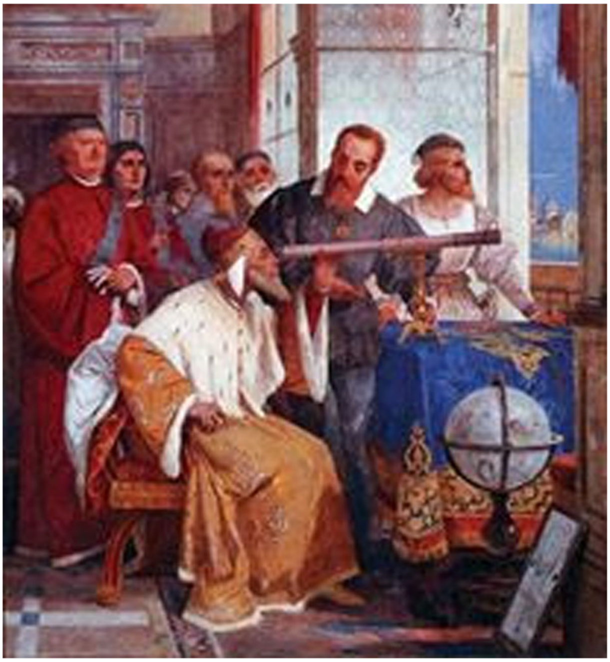

Fig. 5 Galileo Galilei che mostra l'utilizzo del cannocchiale al Doge di Venezia (1858) (reprinted with the permission of Ville Ponti-Varese-Italy)

on how science and society are related, how technology affects both, and how science works. Details about the scene can be asked as part of the re-seeing activity.

Furthermore, using the details on the fresco, the students can discuss the role of the telescope in the field of science. Students can also discuss the interrelationships between science and technology with historical and contemporary examples. Meanwhile, by focusing on the gestures and facial expressions of the men standing backward, the teacher can discuss doubt and skepticism—such as that shown in the facial expression of the man in red robe—and how the skeptical approach to new discoveries in science has always been adopted. The students can then conduct research and/or make presentations by using historical and contemporary examples of how society responds to innovations in science.

Apart from these instructional suggestions, more general questions can be used to trigger discussions and, subsequently, develop the students' reasoning processes. For example, "What do you see in this artwork?" and "What is the most interesting thing here?" are useful questions for the activities to re-see the artworks to expand perception and for initiating discussions that can catch the students' interest. By choosing one or two answers, the teacher can extend the discussion within the frame of the aims of the lesson. Further, by examining the paintings, the students may catch tiny details and utilize such details to reflect upon their ideas or link those with the culture of science.

9 Discussion and Conclusion

The aims of this study are to discuss the need to integrate aesthetic aspects into science education and, accordingly, to propose examples for doing this and achieve the aim of science literacy. The discussion argues that, to meet the needs of contemporary science education focused on bringing up socially responsible and informed individuals, science instruction should help students cross the borders between their own culture and that of science (Aikenhead 1996). Therefore, aesthetic experiences, which combine content knowledge with the beauty of ideas that support the development of humanistic values, have become an important issue in science education. Within this context, artworks can be considered as intensifiers that boost aesthetic experiences and promising tools for enhancing curriculum and instruction given that the use of artworks appeals to the content knowledge, interest, and communication aspects of curriculum. In short, artworks are pedagogically useful for discovering the culture of science and might be effective in meeting the needs of science education.

Given that artworks are not designed and developed within the objectives of teachers or curricula, teachers must work so that the artworks that they choose to use can be adapted to the purpose of instruction. This adaptation process is related to teachers' pedagogical content knowledge, beliefs, and goals (Brown 2009) so they may need assistance in designing instructional materials with the use of such artworks. In this study, the selected artworks and instructional suggestions based on the pedagogical ideas of Pugh and Girod (2007) can be used by teachers to enhance their instruction and promote art-centered experiences in science education. However, the implications of these artworks in real classroom settings would give more realistic results concerning the students' art-centered aesthetic experiences and their role in promoting science education.

The artworks used in this study might be effective tools to simultaneously demonstrate the socio-cultural dimensions of science and the beauty of science. Given that all artworks proposed in this study include details of science, examining and discussing the entire scene or focusing only particular figures, can give teachers a wealth of opportunities to talk about science in general, and the science-scientific community, science-technology, and science-public community interactions in particular. In doing so, the teachers can give students an opportunity to have aesthetic experiences in class. The first fresco includes all the aforementioned aspects, the second fresco concentrates on the science-society and the science-technology interactions, the third frontispiece concentrates on the science-scientific community interaction and the role of women in science, the fourth frontispiece concentrates on the science-public community interaction, and finally, the fifth painting concentrates on the science-authority interaction. The suggested use of these paintings in instruction may enable students to cross the borders between their own culture and that of science, ultimately enabling them to discover the socio-cultural aspects of science. Meanwhile, as emphasized by Flannery (1991), artworks that present the history of science within a socio-cultural context can also be effective in discussing the aesthetic aspects of science and presenting what science is all about. Stories about the characters and the events of the artworks can be used as effective tools for representing the interdependence of science and society.

The proposed artworks and the presented suggestions are expected to fit the methods of individual teachers within the framework of aesthetic understanding, and can be and well-matched with compelling, unifying, and transformative, and unifying characteristics of aesthetic understanding. Given that the presented artworks have rich details and are related to at least one physics concept within a socio-cultural and socio-scientific context, they may compel students to learn more and talk more about the ideas presented, and the teachers can promote this aspect of aesthetic experience by asking questions and promoting deeper classroom discussions. Discussing the characters and the theme of a masterpiece can promote students' reasoning concerning authentic facts, and also help combine cognitive and concept-oriented aspects of science with the aesthetic aspects of science.

As Pugh and Girod (2007) constructed their methods on the transformative nature of aesthetic understanding, the use of related methods, as suggested with the use of related artworks, may lead toward a transformative aesthetic understanding. The selected artworks in this study contain various characters and details about science, technology, and society. Such artworks can also help students realize the inseparable nature of science and society, especially in terms of the effects of the social, cultural, and personal beliefs on scientists. Classroom discussions on the characters, with a focus on the socio-cultural dynamics of science, as well as the similarities and differences between the past and the present may help students expand their views and approach socio-cultural issues via a scientific approach, and gain a better understanding of the socio-cultural dynamics of scientific studies.

Furthermore, by perceiving and understanding the relations between separate characters or items in the artworks, students may experience the unifying nature of aesthetic understanding. Re-seeing activities may also be helpful in enabling students to see the details and connect them with the big picture. Making sense of the big picture can be helpful in fostering greater awareness of social issues, which a scientific literate citizen must possess.

Eventually, the artworks presented in this paper can provide teachers an opportunity to create a medium for aesthetic experiences, thus promoting learning and the creation of socio-cultural meanings (Marshall 2005). However, the goal of encouraging students' active participation in science, with respect to the content of scientific literacy, may not be achieved by just discussing the scenes in artworks. Although students may see, discuss, and understand the socio-cultural settings of science through the selected artworks, they may be perceived as passive receivers of content knowledge. To transform students from passive receivers to active participants Pugh and Girod's (2007) first pedagogical idea (i.e., restoring concepts to the experience in which they had their origin and significance) can be extended by reconstructing historical experiment in physics courses. Thus, students can actively experience the birth of concepts and appreciate their significance.

The use of art is a promising approach in designing a *culturally enriched* physics course; however, there are some possible difficulties. One constraint is how to make the story of the artwork fit in the curriculum. Although finding an artwork related to the interaction between science and society is easier, it is difficult to find the story of the artwork, including characters and the relevant cases. To overcome this problem, a detailed search of the literature should be conducted so that the teachers can produce narratives about artworks in accordance with history. Another solution is to establish a collaboration on creating artworks for science lessons among historians of science and artists. Cases from the history of science that are appropriate to curriculum objectives can be portrayed by artists. Therefore, artworks that are appropriate to both the history of science and science curriculum can be created, and opportunities can be provided for students to have aesthetic experiences within the field of science education. Given that particular artworks represent real events from the history of science, characters, figures, and other details on the scene would be comprehensible enough for the teacher to design the lesson.

Another difficulty is the creative and imaginative aspect of art, which can bring irrelevant characters or items together. Such a scene with irrelevant characters or items may cause misunderstandings for students. For instance, an artist may portray Galileo or Newton as colleagues or depict both the steam engine and the Volta battery as if they are the inventions of the same era. Such artworks may lead to chronological inconsistency and misunderstandings within the context. However, such a difficulty can be turned into an advantage by stressing the roles of former scientists on the studies and discoveries in science and how the subsequent scientists "stood on their shoulders to see further."

Apart from the above, other issues related to the enacted curriculum in science classrooms, such as the required time for teaching a concept in a lesson period, should not be ignored. To overcome this problem on using an art-centered instructional material, strict curriculum objectives should be considered. Teachers should be well informed about the artwork and the art-centered instructional material, the related stories about the artwork, and the supporting questions given to the students so that the lessons are well designed with reference to the curriculum objectives.

Considering the needs of the current science education and the emphasis on scientific literacy, it is clear that educators should make a point of aesthetic aspects of science in science education as well as cognitive aspects of science. Using artworks in science instruction is a way to emphasize aesthetics aspects of science. Discussing scientific concepts within their aesthetic aspects with the use of artworks can facilitate students' engagement in science lessons, help them to discover socio-cultural aspects of science, to expand their perceptions about science, and to transform their ideas to view socio-cultural issues scientifically. Well-designed instructional materials that combine aesthetic and cognitive aspects of science around artworks under a pedagogical framework—like Pugh and Girod (2007) proposed—can help teachers to adapt such curriculum more smoothly. Supporting these arguments, the presented artworks and pedagogical suggestions in this study can promote the integration of artworks in science instruction, and the aesthetic experiences in science education. Further studies on developing instructional materials with the use of artworks can have fruitful results for science education.

Compliance with ethical standards

Conflict of interest The authors have no conflict of interest to declare.

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