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History of science meets history of art on Galileo's telescope: An integrated approach for science education

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Summary

An interdisciplinary approach to science education through history of art is proposed. The approach is innovative, as the artworks complement the history, philosophy and sociology of science contents to increase students' interest and motivation. The approach integrates humanities and science education through history of art, which requests interdisciplinary cooperation of the teachers of the school subjects involved with historical curriculum contents. The approach is elaborated through the case of Galileo's telescope, which provides specific features on the relationships between science and technology (scientific instrumentation applied to generate knowledge), nature of science, and science-technology-society relationships, where history and art meet each other. Further, history of art contributes some contemporary artworks on Galileo case that highlight all those relationships. The explicitness, perception, beauty and accessibility of the paintings may also be a key element to develop teachers' and students' interest and motivation in teaching and learning science through its integration with history of art. Finally, the interdisciplinary educational approach develops a teaching-learning sequence on the basis of Galileo's telescope to guide teaching the issue in science education through history of art. This didactic exemplification elaborates some aims, contents, resources and activities throughout the human, social, philosophical, artistic, scientific and historical aspects involved in the case of Galileo that teachers must adapt to specific subjects, degree and students.

Introduction

From the viewpoint of didactic research on history, sociology and philosophy of science, the inclusion of the history of science (HoS) as a part of science education has been advocated for years and has accumulated many strong reasons to vindicate its use in science classrooms (Dass, 2005; Klopfer, 1963). Nevertheless, current curricula contain few references to HoS, reducing the real importance of HoS as a teaching-learning instrument in science education (SE). Although historical contingency is a universal characteristic of scientific knowledge, historical contexts and HoS tools are often absent in school teaching, so that even proficient science learning becomes incomplete.

Further, the pervading positivism focuses mainstream SE on the final forms of scientific knowledge, e.g., finished, definitive, unquestionable, and without context, ready to be learned by students (euphemism for rote learning to overcome their cognitive difficulty). This dominant and persisting focus of SE on teaching concepts and processes of science (the Vision I of science literacy according to Roberts, 2007) has deleted HoS and contexts from school science classrooms (Milne, 2011). The consequence for student learning is an appalling distortion of the nature of science (NoS), the second component of science literacy or Roberts' Vision II, as mainly naive positivist conceptions of science are conveyed to students (Abd-El-Khalick & Lederman, 2000).

This article aims to recover HoS for SE as a way to reach science literacy for all through informed NoS via a new interdisciplinary pathway: adding art to science. Further, art may contribute to make SE more interesting and motivating for students. On the one hand, artworks, especially painting, may make science more understandable for students due to the attractiveness of the direct plastic messages of art, and on the other hand, the artworks are easily available through digital media. In addition, the pathway from art to HoS is simple and direct as both share the historical contexts that may lead students to informed NoS views on scientific achievements. Speiser (2011) explored this thesis wondering, “What can a historian of science learn from a historian of fine arts?” and elaborating on the many similarities of science and arts to conclude that the historian must transmit all of them. The art-science similarities involve not only the fine arts, but all kinds of arts (architecture, jewelry, music, language, etc.). Speiser even claims that, “Nothing needs to be said of the role … of the artist of the Italian Renaissance in modern science: how many artists of those periods were scientists and vice versa?” (p. 42). For this purpose, the historian of science must join colleagues and other contemporaries.

The history of art in SE is a pedagogical innovation, given the traditional division of school subjects--science, history, art, language, maths, etc.--and the cultural separation between science and humanities disciplines. However, in educational settings of many countries, art and science are school subjects whose curricula provide the HoS and history of art common contents. This situation facilitates the educational complementarity between science and art through HoS and art and the teachers’ mutual collaboration to enact the innovation of teaching HoS and NoS through art in school SE (Milne, 2011).

In the long term, this article also aims to encourage science teachers to teach students how science works across the historical, sociological, and philosophical aspects that stem from the HoS and art case analysis on Galileo’s telescope. This teaching aim unfolds in some students’ specific learning objectives on NoS literacy through art scaffolding, such as increasing the understanding of the role of observation and instrumentation in scientific research; the involvement in the historical relationships between paintings and science contents; the appreciation of the multiple social interactions affecting science in the making or shedding light on community concerns; and particularly on the motivation and interest for SE learning.

History of Science as Curricular Content

SE research has proposed a variety of ways to include HoS as curricular content and has generated a number of justifications for doing it[1]. A synthesis of the reasons follows:

- to increase students’ motivation and admiration for science and scientists
- to develop better student attitudes toward science
- to humanize science
- to show science as a collective and individual endeavor
- to understand and appraise the interaction between science and society (contexts)
- to account for the way science validates knowledge
- to disclose the relationship between science and technology
- to make SE more challenging
- to improve students' reasoning developing higher order thinking skills
- to contribute to better comprehension of science content
- to link science and other school subjects, with particular emphasis on the humanities (reducing the gap between the “two cultures”)
- to improve science teacher training
- to connect the different scientific disciplines and
- to identify the false alternative scientific conceptions.

This study takes into account all but the last two above mentioned theoretical justifications of HoS as a function of their connection to the history of art.

Models for Teaching History of Science

There have been many teaching approaches to HoS in SE research. To deal with this complexity, McComas (2011) proposed a taxonomy in order to systematize how HoS content can be used in SE. This taxonomy assumes that the different approaches to HoS are not equivalent, because their integration within science teaching is not equally easy, mainly due to

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[1] For example, among many others Kitcher (2011); Matthews (1994); Monk & Osborne (1997); Rasmussen (2007); Rudge & Howe (2009); Sherratt (1983); Wider (2006).

their different demands on teachers and students, or their different impacts on students learning (Allchin, 1997).

The taxonomy includes the following categories (McComas, 2011):

1. Interaction with texts of original works (or extracts of them)
    a. Complete original works (which may include additional comments)
    b. Summaries of the original works, which may include additional comments
2. Case studies, stories, and other similar illustrations of HoS, including original written materials
    a. Cases studies, with original content
    b. Histories of science
    c. Illustrations, cartoons and short examples
3. Biographies and autobiographies of scientists and their discoveries
    a. The autobiography of a scientist
    b. The biography of a scientist (written)
    c. The biography of a scientist (dramatic presentation)
4. Book-sized presentations of some aspect of HoS
    a. The description of a general HoS
    b. The history of a specific scientific discipline
    c. The history of a scientist or a particular sub-discipline
    d. The history of a particular discovery or event
    e. The description of classical experiments
5. Role games and activities related to historical characters
6. Textbook insertions related to HoS
7. Replication of experiments and other “practical approaches” to become involved in the historical aspects of science.

Some of the former categories to be exemplified within the case of Galileo's telescope and art integration are case studies, stories and other similar illustrations of HoS, biographies of scientists and their discoveries and replications of experiments.

Further, HoS in SE leads to an unavoidable counterpart: teaching HoS means teaching how science works, or the NoS (Kitcher 2011). All scholars agree on the importance of NoS for scientific literacy, yet they present different versions of NoS, which spread from some consensus lists to the currently advocated holistic and inclusive view of the NoS approach, where all the features related to how science works, philosophical, sociological, historical, economic, psychological, political, etc., are integrated to be taught in SE; to achieve this NoS literacy, HoS is one of the most advocated ways (Erduran & Dagher 2014; Manassero-Mas & Vázquez-Alonso, 2019).

In this regard, researchers indicate that effective teaching of NoS, and, therefore, HoS, requires three key elements (Abd-El-Khalick & Lederman 2000; Deng, Chen, Tsai & Chai 2011): NoS content should be explicitly integrated within science syllabi, the pedagogy of NoS, and therefore, of HoS, should be reflective, i.e. centered on promoting student activity, and the cognitive demands should be appropriate, interesting and motivating for each age group. This paper proposes a teaching learning sequence plan based on Galileo’s telescope and art that explicitly develops some aspects of NoS involved in this historical case.

Art and Science

Aristotle defined art as “a permanent disposition to produce things rationally”; Quintilian noted its regulated aspect, as the art is based on a method and an order, and Plato highlighted the human creative capacity to make things through intelligence and learning. Accordingly, any productive human ability or skill that was subject to rules or specific precepts, and suitable to learning, evolution or improvement, e.g., making objects, directing an army, convincing the public in a debate, performing measurements, etc., was considered art in the antique Greco-Roman times.

The word “art” stems etymologically from Latin (ars, artis), which in turn comes from Greek (techne). The first Spanish dictionary (1611) defined art as “recta ratio rerum faciendarum,” and the current Spanish dictionary (*Real Academia Española*, 2014) defines art as:

> The capacity or skill to make something; demonstration of human activity through which reality is interpreted, or imaginary things are represented with plastic, linguistic, or sound resources; a set of precepts and rules needed to make something; skill, cunning; someone's personal disposition; logic, physics and metaphysics, etc.

Likewise, the Cambridge Dictionary (Cambridge University Press, 2017) defines art as “the making of objects, images, music, etc. that are beautiful or that express feelings; the activity of painting, drawing, and sculpting; an activity through which people express particular ideas.” All these definitions allow scholars to conclude that little has changed in art conception and emphasize the integration of art with technique, both understood as the capacity to produce something following rules or methods, susceptible to change, improvement, and learning. Many artworks, from water-clocks to pyramids and cathedrals, prove that artisans had a precise technical knowledge long before science had been developed and underline the many coincidences among all of them, in order to oppose sharp discrimination (Speiser, 2011).

Currently the ancient integration of art with science appears broken in various contexts, especially education, through the disciplinary segregation of different school subjects. The current separation of art and science is a result of their divergent historical evolution so that the two terms, art and science or technology, are far away from synonyms, which lead Snow (1987) to coin the two culture constructs. According to Snow, the current separation between the so-called humanities (arts, history, language, jurisprudence, philosophy, religion, ethics, etc.) and sciences (science, technology, engineering and mathematics) is manifest in academic and daily life as a by-product of their historical evolution. On the one hand, arts are considered part of the broad human culture, inasmuch as they fulfil the aesthetic, pedagogical, ornamental or commercial aims, ideas and values of human mind across space and time. On the other hand, sciences are also products of the human mind by other means, yet sciences are perceived by the public as somewhat esoteric knowledge that is cultivated by a minority of experts (scientists). Snow upholds that a humanist and a scientist of the second half of the 20th century would have little in common, and this situation is due, in part, to some philosophies of science who exclude social and human values from science. Further, some philosophers reject the equivalence of arts and science, as they both developed autonomously throughout history, with different goals and leading to different cultural results (Levy-Leblond, 1996). Therefore, sciences have not traditionally been considered part of the human culture through the same logic as humanities, although both are products of the human mind.

Other philosophers claim that the debate between speculative humanities (classical philosophy and arts) and experimental sciences (science, technology) spanned for centuries. During the 18th century the status of experimental results on steam, engine, machines, manufacturing and mechanical arts increased due to their use in the satisfaction of human needs through the incipient industrialization (Rossi, 2002). Current science and technology are quite pervasive in knowledge societies, yet their cultural status in public opinion does not equal arts or humanities. However, an alternative view considers arts and science/technology as cultural entities that are not so clearly separate, because they share some epistemological similarities (creativity, imagination, aesthetics, social impact, institutional activity, etc.), suggesting deeper relationships with each other through architecture and engineering design, digital art, communication technologies and the like. Both involve creative activities and intellectual and material products made by humans for the advance of ideas and knowledge about the world and the satisfaction of vital human needs. Historian Misa (2011) examined “the question of technology” and developed a masterful analysis on how science, technology, society and culture have influenced each other over five centuries. This same claim has been extended to science through social studies of science that make explicit the interrelationships between science, scientists, technology, and society; the science-technology-society (STS) paradigm developments for three current SE frameworks of research and teaching: socio-scientific issues, teaching issues with scientific content and social impact; scientific literacy for all, teaching science for non-scientists; and the nature of science, for teaching how science works (Vázquez-Alonso & Manassero-Mas, 2019).

Today science provides tools and technologies that allow arts to advance in many areas, such as art materials, forgery, electronic music, computer graphics, chemistry of pigments, UV, X-ray and spectroscopic analysis, conservation and authentication techniques, etc. (Del Federico, Diver, Konaklieva & Ludescher, 2002). Conversely, the arts interpret the abstract concepts of science, space, time, light …, in order to understand them within the non-scientific daily human experience (Arapaki & Koliopoulos, 2011). For instance, medicine has had a long tradition throughout centuries in paintings due to its overall impact on social culture (Ríos & Solbes, 2008). This comprehensive science/art approach is currently established in the so-called medical humanities, where, through humanities (writings, history, paintings,…), we can

> "… show medical students how humanities and the arts can help them develop both critical thinking and empathy to better understand their patients' illness experiences, the doctor/medical team-patient/family relationships, physician self-care, and various other aspects of healthcare… or …enrich our lives in medicine, increase our ability to observe, help us understand perspectives other than our own, shed light on community concerns, expose our assumptions, and provide a means for grappling with the inherent uncertainty in medicine"[2].

From the educational view, scientific literacy for all citizens synthesizes the concept and consideration of science as an essential part of the human culture, and therefore, is interdisciplinary, integrated with other elements like art beyond academic and school divisions. Scientific literacy represents an attempt to recover and vindicate science and technology education, which must be accessible for everyone as part of the human culture (Allchin, 1997). Within this framework, in order to attain true meaningful learning for all citizens, the popularization and teaching of the relationships between art and science develops two approaches: the interdisciplinary approach that promotes the use of artworks for teaching science issues (Galili, 2013), and the didactical transposition that reframes teaching knowledge through authentic elements of social practices (Arapaki & Koliopoulos, 2011).

On the side of art, the reverse movement, which tends toward integration with science, is also detected. In recent historiographic publications (Galluzzi, 2009) about the target period of this paper (16th - 17th centuries), a tendency toward the integration of the approaches of diverse disciplines, such as history of art, cultural history and HoS is also observed, leading to the expansion of the interdisciplinary paradigm for studying modern science, and giving rise to the prototype of the artist-engineer like Leonardo da Vinci in Italy and Juanelo Turriano in Spain. Thus, representations and images of the natural and scientific world produced by artists have become an excellent tool to analyze and interpret science, offering a rich and complex panorama of its historical development (Marcaida, 2014). From a philosophical viewpoint, creativity and imagination have been claimed as major epistemological abilities both of scientists and artists (Miller, 1996; Harré, 1985). Further, the scientist's joy when making a new discovery and the artist's exultation are similar; beauty does not dwell only in the fine arts: a proof can be beautiful, a theory can be admirably organized, and an experiment can be brilliantly conceived (Speiser, 2011). Maeda (2013) enlarges this integrative trend between art and science with the rationale that artists and scientists tend to approach problems with similar open-mindedness, inquisitiveness, and big-question approach (What is true? Why does it matter?). Thus, he advocates the educational integration of Art-Science-Design by developing new pedagogical frameworks for educators and

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[2] Program in medical humanities and arts, School of Medicine, University of California, Irvine, at https://www.meded.uci.edu/student-life/medical-humanities.asp and Program for Humanities in Medicine at Yale Medical School, http://medicine.yale.edu/humanitiesinmedicine/

policy makers that lead STEM (Science-Technology-Engineering-Mathematics) studies to become STEAM (STE-Art-M) studies in the educational system. All in all, these trends refute the idea of the “two cultures” so embedded in current common-sense thinking and academia, and underline the union (rather than separation) inherent both in scientific and artistic creative thought.

Further, some attempts have been made to underline the relationships between science and art in SE. Galili and Zinn (2007) discussed examples of artworks that could help students to understand the optical concepts of science curricula, and at the same time would challenge their attention to the scientific aspects of the artworks, thus promoting a culturally rich learning that highlights the complementarity between science and art. Moreover, Galili (2013) advanced this position on the influence between art and science (they both seek to represent certain truths of reality), using many pictorial artistic images to support scientific (again, optical) concepts as well as the (abstract) NoS conceptions and students’ engagement through the aesthetical and emotional arousal of art as a new context to prompt their motivation. Along the same line of crossing borders between science and humanities, Braga, Guerra and Reis (2013) developed a complex approach to teach the historical transformation of the physical concepts of space and time (Aristotelian, Newtonian and modern) with the help of pictorial artworks, highlighting the embeddedness of science and scientists in human culture. However, the rationale involved in these research studies may be hard to follow for a science teacher as the studies address abstract and complex concepts of physics and epistemology beyond the teachers’ current training. Further, art can contribute to SE in a much simpler way, providing understandable historical evidence for science knowledge.

The Origins of the Telescope: The Manufacture of Lenses

A feature of the social studies of science and technology states that techno-scientific practices require supportive social contexts, which are embodied in social, institutional, and cultural systems that allow advancements at a given historical moment (Vázquez-Alonso, Aponte, Manassero-Mas & Montesano, 2016; Pacey, 1983). This section presents the social and cultural system that made possible the birth of the telescope, the instrument Galileo used to enlarge scientific knowledge.

In the aftermath of the 16th century, the inventions of microscopes and telescopes were based on a craft of lens construction, which the master glassmakers had developed to produce lenses to correct vision defects during the previous centuries. This craft became a thriving industry that also met the need of good quality lenses for these two scientific instruments. For a time, Italy was the center of this enterprise, as Italy owned the main sources of quality glass in Murano and Florence, and Italian glass was sought and used by European manufacturers of lenses. Further, the Netherlands also developed an effective manufacture of lenses, to the extent that the city of Middelburg is believed to be the cradle of the telescope (van Berkel, 2010).

At the end of the 16th century, the problems involved in preparing glass for manufacturing eyeglasses and mirrors--grinding and polishing lenses--were noted before. A detailed discussion of this topic is included in the book entitled *Magiae Naturalis* by the Neapolitan Giovanni Battista della Porta, dated 1589, offering the first description of lens construction with Venetian glass referring to the balls of glass (“Pilae Vitrae”) that were cut in small circles in the form of a lentil (from which its name, lens. arose), then polished to make the eyeglass lenses. The production of lenses for microscopes and telescopes took advantage of the machinery and techniques developed by the artisan glassworkers (Willach, 2010).

The *Treatise of Optics* by Giovanni Christoforo Bolantio addresses the patterns, the machines and operations to make lenses: trays to make concave patterns; the tools to grind the glass; the glue to hold the lenses into frames; and the special secret to shape white glass to make lenses. Furthermore, Bolantio’s treatise presents several empirical tables that relate the dimensions of the telescope tube and the lenses: the length of the tube (in feet) to the aperture diameter of the convex lens, the length, the curvature radius of the biconvex lens and twice the curvature radius of the biconcave lens, and the length of the tubes, twice the curvature radius of the lens (see reproductions in Bedini & Bennet, 1999).

These data confirm that Bolantio’s treatise was presumably written without any theoretical knowledge of optics, because there are no references to focal lengths of lenses, and only contains empirical data on macroscopic parameters of the telescope elements (tube lengths and curvature radii of concave or convex lenses), whose relationships were probably obtained by trial and error experiences in the construction of telescopes. Extensive descriptions of the mathematical and optical knowledge of the time and some tentative intuitions about Galileo’s mastery of this knowledge are detailed in the doctoral thesis of Dupré (2002).

The methods applied to grind the glass for spectacles and mirrors were modified to meet the higher quality needed for the lenses, yet the construction changes were insufficient to achieve the adjusted shape, total clarity, and perfect polish required for lenses of scientific instruments. These high demands were meant to prevent the extended defects of lenses such as the presence of bubbles, foreign bodies, and the mixture of different glasses that led to bad vision. From the outset, efforts were made to produce quality optical glass in Europe, yet without success. Throughout the first half of the 17th century, both in Venice and Florence, master glaziers tried several techniques and machines to improve glass quality, yet the best glass did not reach the standards for adequate optical vision. By the second half of the 17th century, only minimal progress was achieved, which did not resolve any of the problems to improve quality through reducing chromatic and spherical aberrations (Bedini & Bennet, 1999).

The Venetian masters, Girolamo Magagnati and Giovanfrancesco Sagredo, and craftsmen Giacomo Bacci and Master Antonio, all mentioned in Bolantio’s book, presumably provided lenses for Galileo from 1611 to 1619. A Venetian glass maker called Armagno, who had a reputation for producing the best lenses of the time, is also believed to have made the most successful lenses for Galileo.

Due to poor quality and aberrations, only a few lenses of the many produced were suitable: for example, only 22 lenses were usable out of the 300 lenses (three lire each) sent by Master Bacci, as Galileo’s letter reported. In 1618, reference is made to Sagredo’s trials to improve quality of the lenses, but all his experiments failed. The move of Galileo from Venice to Florence in 1615 was motivated not only to seek the protection of the Medici, but also because the quality of glass and the casting processes to make lenses in Florence (master Ippolito Francini was Galileo’s manufacturer) acquired a better reputation than those of Venice, yet the technical problems to obtain acceptable lenses remained unsolved up to the death of Galileo (Bedini & Bennet, 1999).

The Origin of the Telescope and the Debate over its Invention

The telescope very quickly evolved from being a simple optical entertainment to see distant objects as if they were close up, to being a philosophical artefact to allow military and navigation applications and the creation of new knowledge about the natural world, which we currently call a scientific instrument, or technology instrumentation for scientific research (Bedini, 1964). The scene of Figure 1 reflects the courtesan life of the times that exemplifies the use of this instrument as a courtly entertainment: several persons play different instruments around a table in a garden, while the gentleman standing at the left contemplates a lush garden through a telescope (the cultural system for technology).

Figure 1

David Vinckboons I (attributed to), Courtesans in a garden, ca. 1610-1625, oil on wood, 51.2 x 82.2 cm, Sotheby’s London (auction 1995-07-05, lot nr. 283).

The advent, origins, and the seeking of the inventor of the telescope have a long tradition among historians as an important episode in the HoS and technology. This importance is multifaceted: the fact of inventing a new instrument, its impact on changing the image of the universe, and the radical transformation of the epistemology and practices to gain knowledge about the natural world.

In the Dutch town of Middelburg, the manufacturer of lenses, Johannes Lipperhey (or Lippershey, or Hans Lippersein) applied for the first patent of the instrument in 1608, which was rejected. Over the years, the credit for first inventor of the telescope has had numerous competitors from different countries: Lipperhey, Metius, Jansen and Drebbel from Holland; Girolamo Fracastoro, Gualterotti, Della Porta and Galileo from Italy; Roger Bacon, Digges and Bourne from England; Velser and Marius from Germany; Juan Roget from Spain; and Abul Hasan from the Arabic world (Dupré, 2010).

The book *Telescopium* (Sirtori, 1618), written around 1612, tells the story of one of Lipperhey’s clients, who had commissioned the optical craftsman to make a set of concave and convex lenses. When he picked up his order, the customer naively carried out some tests in front of the craftsman by aligning a concave lens with a convex lens and moving them forward and backward and looking through them. The craftsman's curiosity led him to repeat the customer's trial, and immediately realizing the importance of the finding, which he completed by putting the two lenses into a tube and claiming the patent to Prince Maurice (The Hague). Whatever the account, the combination of two lenses to observe closer the objects is the kind of discovery with high chance of occurring in the context of people related to lens manipulation.

Figure 2
Florentine painter, Portrait of Galileo Galilei with telescope and ring of the Accademia dei Lincei, 1640-1645, oil on canvas, 78 x 64 cm. Florence, Galleria degli Uffizi (inv. 1890, Nr. 5432)[3].

Modern historians have proposed that the invention of the telescope was probably a long and depersonalized process, in which possibly many people were involved (social organizational system) to develop something that originally was only an optical toy (Dupré, 2010). De Waard placed its origin in Italy about 1590 (cited by van Helden, 2010, p. 3), and then it would have moved to the Netherlands. However, van Helden (2010) shifted the focus of research from the specific questions about where and who invented the telescope toward how the telescope developed, because for many years, it was simply a device known and used as a “diletto” (entertainment) in some wealthy circles of the time. Possibly, too, it was not invented in a concrete place by a concrete person (Dupré, 2002). Lipperhey’s patent application was rejected, because it was reclaimed by other alleged inventors (undeniable proof that the instrument was already known by some people in 1608, and therefore, the telescope had been “invented” years ago). Then, the news spread throughout Europe, and

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[3] Galileo holds in his right hand a telescope, which presents notable similarities with the one built by him around 1610, after entering the service of the Grand Duke of Tuscany, Cosimo II de’ Medici (Galluzzi, 2009), which is part of the preserved Medici collections, currently in the Istituto e Museo di Storia della Scienza, Florence (inv. n. 2428).

copies of the instrument reached various governments (Dupré, 2002; Zuidervaart, 2010). In sum, the origins of the telescope constitute an intricate and long process with many steps and many actors (social organizational system).

With this development, the historiographical concept of circulation of knowledge plays a key role. Accordingly, a primary factor of the development of the telescope would have been the progress of the manufacture of quality lenses, as the theoretical knowledge of optics was scarce and sometimes contradictory. Secondly, some efforts to build telescopes with concave mirrors during the 16th century were unsuccessful because mirrors required higher quality than lenses (as we know today, but not known at that time). Thirdly, the circulation of knowledge in the origins of the telescope was fueled by its importance for navigation and militia. All these processes of circulation and appropriation of new advances and knowledge turned the telescope into a technological and cultural artefact that was continually being redesigned since its origins (Vermij, 2010). All in all, these data frame the science-technology-society context for learning on the telescope and art.

Table 1

Technical features of the first telescopes built by Galileo preserved in the Istituto e Museo di Storia della Scienza in Florence

	Telescope A		Telescope B	
Inventory N.	2427		2428	
Date	Ca. 1610		1609 - 1610	
Materials	Wood, paper, copper		Wood, skin	
Length	1273 mm		927 mm	
Increases	14		21	
Visual field	15’		15’	
	Lens assembly			
	Objective	Ocular	Objective	Ocular (original lost)
Type	Biconvex	Flat-concave	Flat-convex	Biconcave
Diameter	51 mm	48.5 mm	37 mm	22 mm
Focal length	1330 mm	- 94 mm	980 mm	- 47.5 mm
Thickness	2.5 mm	3.0 mm	2 mm	1.8 mm

Note. Data retrieved from http://brunelleschi.imss.fi.it/museum/esim.asp?c=405001

The Origins of Science and Galileo's Telescope

Galileo Galilei (Pisa, 1564 - Rome, 1642) is considered an important contributor to the scientific revolution that started in the 17th century a new way of studying and analyzing nature, which is known today as science. Galileo was familiar with Copernicus’s heliocentric proposal to explain his astronomical data with utmost prudence, because Copernicus was aware of its cultural impact. Although Galileo's discoveries are numerous in diverse areas and activities, this study focuses only on those related to the telescope, such as the chosen example of the meeting of science and art (Figure 2).

It seems that, in Venice, in around 1609, Galileo found out that Lipperhey had patented an optical instrument (spyglass) formed by a flat-concave lens and another flat-convex lens aligned in a tube, which allowed seeing expanded distant objects (3x). Biagioli (2010) argues that Galileo probably saw a telescope of his friend Paolo Sarpi immediately before building his own, which he presented to the Senate and Dux of Venice (August 24, 1609).

Figure 3

Detail of the eyepiece of a telescope attributed to Galileo (inv. N. 24247) Istituto e Museo di Storia della Scienza, Florence.

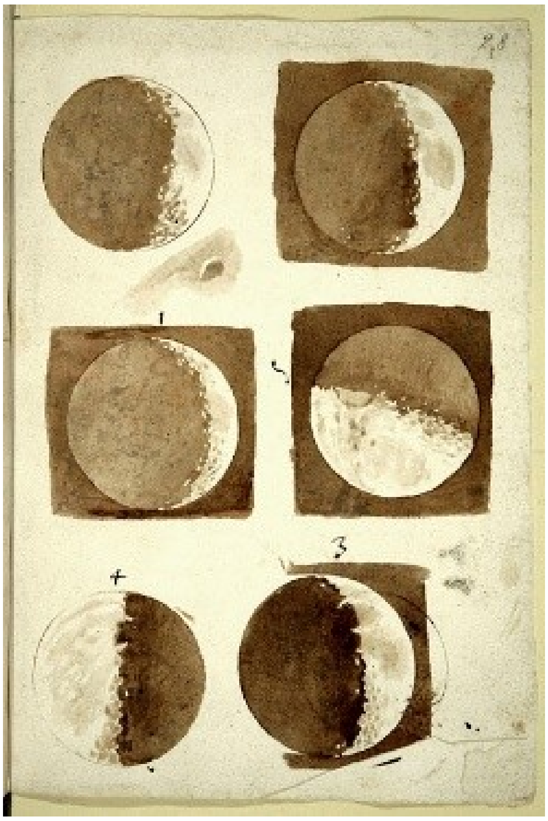
Note. Retrieved from http://brunelleschi.imss.fi.it/museum/esim.asp?c=405001

Galileo immediately used this instrument for looking at the sky to expand astronomical observations, and thereby, to refine and confirm his findings, by extracting new and original scientific and decisive meaning from the telescope (Biagioli, 2010). Galileo devoted his efforts to improve his telescope, based on his extensive artisan experience through the construction of practical devices (air thermometer, geometric compass, water pumps, pendulums, and projectiles) and from the glass manufacturers of Venice and Florence to get the lenses he needed. Presumably, Galileo had hardly any clues about the patented telescope but had solid mathematical knowledge, and also probably knew some theoretical optical principles through Della Porta’s writings (Dupré, 2002). This background allowed him to build soon a refractive telescope with higher resolution and magnification (20-30x) through successive trial-and-error tests. Recently, Zik and Hon (2017) argued that Galileo most likely realized that objective and eyepiece make up a system and accordingly proceeded with this innovative optical insight.

Galileo built dozens of telescopes, which he generously gave away to patrons, protectors and personalities, to earn their economic favor and support. Table 1 summarizes the technical features of two Galilean telescopes, and Figure 3 displays one of them.

Since the end of 1609 and up to early 1610, Galileo performed observations of the Milky Way and other star clusters with his telescope. He observed on the moon mountains and craters, unequivocal evidence of the satellite's similarity to the Earth (Figure 4). The significance of this discovery was huge, as it contradicted the Aristotelian thesis sustained until that moment: the perfection of the celestial world required the perfect circularity of orbits and stars, which was falsified by the mountains and valleys on the moon. The observation of the four satellites of Jupiter is further evidence against the Aristotelian geocentric system in its obvious contradiction that the earth is the center of all circular movements in the heavens.

Figure 4
Galileo Galilei, drawings of the Moon, November – December 1609, Florence, Biblioteca Nazionale Centrale, Ms. Gal. 48, c. 28 r. (showing craters, mountains, valleys and plains).



Galileo also observed that the planet Venus showed phases resembling the moon’s phases. Resorting to Copernicus' heliocentric hypothesis, assuming that Venus rotates around the sun and not around the earth as the geocentric system had held for centuries, Galileo's interpretation of the observed phases of Venus was simple and convincing, and Galileo’s explanation once again refuted geocentrism as it involved Venus spinning around the sun.

Galileo was quick to publish his observations and interpretations in *Sidereus Nuncius* (March, 1610), which made him famous all over Europe and emphasized the advantage of instrumentation (telescope) for astronomical observations. Galileo dedicated the book to Cosimo II de” Medici, and assigned the name Medici Stars to Jupiter's moons, which represented the virtues of Cosimo I, who had obtained such virtues directly from Jupiter and would have transmitted them to his successor by means of the Medici Stars and Galileo himself, as an intermediary for that astrological-dynastic encounter by revealing the existence of the stars (Biagioli, 2008). This correspondence between the Medici Stars and the four virtues was translated into the plastic arts, and, decades after Galileo's conviction, the image of the four virtues as representations of the four stars would still take part of the allegorical imaginary of the Medici family, further evidence of the deep connections between science and art.

However, the German astronomer, Simon Marius, disputed Galileo’s priority for discovering the moons of Jupiter. Marius defended his priority using dates from the Julian calendar, whereas Galileo used the new Gregorian calendar, resolving the dispute for Galileo, yet both probably making the discovery independently. Conversely, Marius beat Galileo in the dispute over the eponymy of Jupiter’s moons, as the current names of moons are those proposed by Marius (Europe, Io, Ganymede and Calisto), instead of Medici stars (van Helden, 2010).

Probably already established in Florence, Galileo studied sunspots in 1611, although he had observed them previously. In that year, Galileo went to Rome and showed the sunspots to diverse personalities; the displays with his telescope made his stay triumphal, and Federico Cesi appointed him member of the Accademia dei Lincei (Figure 2), the first scientific society founded by Cesi in 1603 (Sobel, 1999).

Figure 5

Christoff Thomas Scheffler, Portrait of the Jesuit Christoph Scheiner, 18th Century, oil on canvas, Stadtmuseum Ingolstadt.

In 1613, Galileo published the history and interpretations of sunspots and their accidents, under the patronage of the Grand Duke of Tuscany. In the same year, the sunspots had been observed and published under a pseudonym by the German Jesuit astronomer Christoph Scheiner. Galileo's publication originated two scientific controversies: a theoretical controversy against the interpretation of Scheiner (Figure 5), who argued that the sunspots were caused by stars near the sun and interposed between the sun and earth and initiated a practical controversy for the priority of the discovery. The latter earned Galileo the hostility of the Jesuit to the point that this animosity may have led to the process against Galileo initiated by the Inquisition 20 years later (Sobel, 2000).

According to van Helden (2010), the technical limitations of Galileo's telescope (narrow visual field and restrictions of magnification) meant that, in around 1613, Galileo and the astronomers had already carried out all the fundamental observations that allowed the telescope of that time. New discoveries needed lenses without aberrations to achieve greater magnification and image quality. This advance did not begin until 1640 through the development of the Keplerian telescope shortly before the death of Galileo.

Science Meets Art: Galilean Illustrations in Artworks

This section aims to demonstrate how the contemporary art of Galileo’s times acted as social cultural means of disclosure and communication of Galilean science to the public of the time (probably aristocracy or bourgeoisie), through the representation of the instruments (in this case, telescopes) and scientific discoveries in artworks. Simultaneously, like any self-respecting media, they reveal fierce competition for the primacy of authorship in the representation of scientific breaking news in artworks.

Figure 6
José de Ribera, The Allegory (Sense) of Sight, 1615-16, oil on canvas, 114 x 89 cm. City of Mexico, Franz Mayer Museum.

The first example is *The Allegory (Sense) of Sight* of José de Ribera, el Españoleto (Játiva, 1591 - Naples, 1652), painted in Rome for a Spanish client (Figure 6). A man stands in front of a table holding a telescope of about one meter in his hands; some rings can be seen along the tube, one ring between the ocular and objective, and other rings holding the lenses; several objects, including eyeglasses, lie on the table.

The importance of this artwork also stems from the correspondence between the literary portrait of technicians of the time (presumably the Cremonese engineer and watchmaker Turriano) made by the humanist Marco Girolamo Vida (Spinosa, 2008, p. 45) and the pictorial representation of the man in *The Allegory of Sight*. This correspondence is far from casual, but rather matches the style of the time, namely exaggerating physical and intellectual characteristics to produce a stereotypical representation of genius and the man of science, which became commonplace at the time (Zanetti, 2015). Besides the stereotypical representation of genius, Mason (2012) highlights that the most surprising element in *The Allegory of Sight* is the presence of the telescope, as few people could own such an object when the portrait was presumably painted (1615). Thus, Mason catalogs this artwork as intellectual realism, taking into account both the telescope and the stereotypical character's appearance representing the genius.

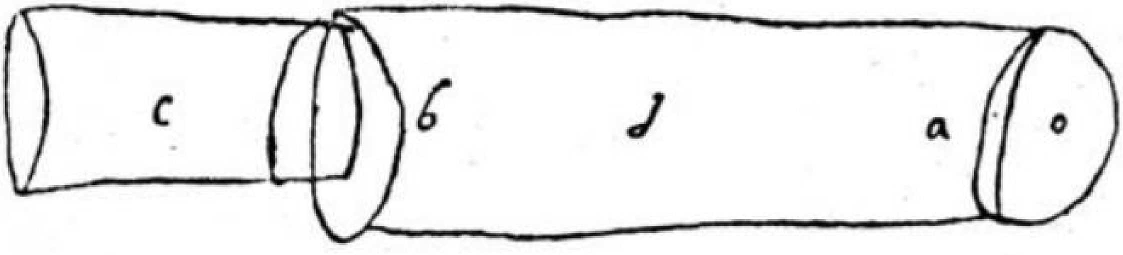
Figure 7
Jan Brueghel the Elder, Landscape with view of the Castle of Mariemont, ca. 1608-1611, oil on canvas, 84.7 x 130.8 cm. Richmond, Virginia

Museum of Fine Arts, The Adolph D. and William C. Williams Foundation (inv. nº 53.10), detail of the lower left corner.

Although Tosi (2007) held that Ribera's picture contains the first painted representation of a telescope, Mason (2012) and Bucciantini, Camerota, and Giudice (2012) attribute this pictorial priority to the work, *Landscape with a View of the Castle of Mariemont*, by Jan Brueghel the Elder (Brussels, 1568 - Ambers, 1625) and dated around 1611 (Figure 7). This picture shows a small figure that corresponds to the Archduke Alberto, Governor of Flanders and patron of the painter, observing a flying bird with a telescope. It has been documented that the Archduke bought two telescopes for 390 guilders in May of 1609, a month after signing the Peace Treaty between Spain and the Netherlands. Taking into account that the presumed date of Lipperhey's first patent in the Netherlands was October of 1608, we can infer a rapid development of the telescope construction industry, possibly due to a great demand for them, because the telescope was an instrument for use on naval or military purposes (Vermij, 2010).

Figure 8

The oldest known sketch of a telescope, drawn by Giovanni Battista della Porta in a letter to Federico Cesi on August 28, 1609. Rome, Biblioteca dell'Accademia dei Lincei, ms. XII, cc. 326r-v, 332v.



Nevertheless, Mason (2012) points out that the most accurate statement is that *The Allegory of Sight* by Ribera is the first known painted representation of a Galilean telescope, because the instrument is identified as one of the many telescopes designed by Galileo, specifically, the one he made for the University of Padua in 1609, subsequently given to the Pope (towards 1611). It is documented that Galileo used to give away telescopes to his protectors (Venetian Senate, Cosimo de' Medici, etc.) to win their favor and ensure his wages, as well as to other personalities with whom he had differences, such as Cardinal Francesco Maria del Monte or Cardinal Bellarmino (Spinosa, 2008).

Mason (2012) documents the existence of telescopes in Rome prior to the arrival of Galileo in 1611, which suggests that these Roman telescopes either came from other places, or they were built there, therefore, simultaneously and independently of Galileo. The correspondence among members of the Accademia dei Lincei shows that President Cesi probably built various telescopes in Rome and distributed them among personalities, as his sketch of a telescope in 1609 gives evidence (Figure 8); further, Cardinal Scipione Borghese received a telescope from Flanders in 1609. Amazingly, the Roman telescopes and those of Galileo when he visited Rome in 1615 held similar quality.

To continue the artistic portrayal of the telescope, two artworks of Jan Brueghel the Elder are considered. Although they have been widely studied from different disciplinary fields (Campo y Francés, 1982; Díaz Padrón & Royo-Villanova, 1992; Marcaida, 2014), the presence of the telescope has paradoxically been circumvented, with the exception of Bucciantini and colleagues (2012), who briefly refer to its presence in the *The Sense of Sight* (Figure 9). This painting (similar to Ribera's painting) is part of an allegory of paintings devoted to "the five senses," yet Brueghel's painting would be considered within the Flemish pictorial tradition of so-called "cabinet paintings" (representations of exuberant courtier interiors where sets of scientific and measurement instruments related to the sense of sight are particularly relevant). Various authors have stressed the link of the room represented in this painting with the Archdukes Alberto and Isabel Clara Eugenia (Díaz Padrón & Royo-Villanova, 1992), which again reveals these patrons' interest as collectors, both in art and science objects. The presence of these objects in a collection, and more specifically the possession of scientific instruments like telescopes or clocks has been interpreted as a symbol of social status (Bucciantini et al., 2012).

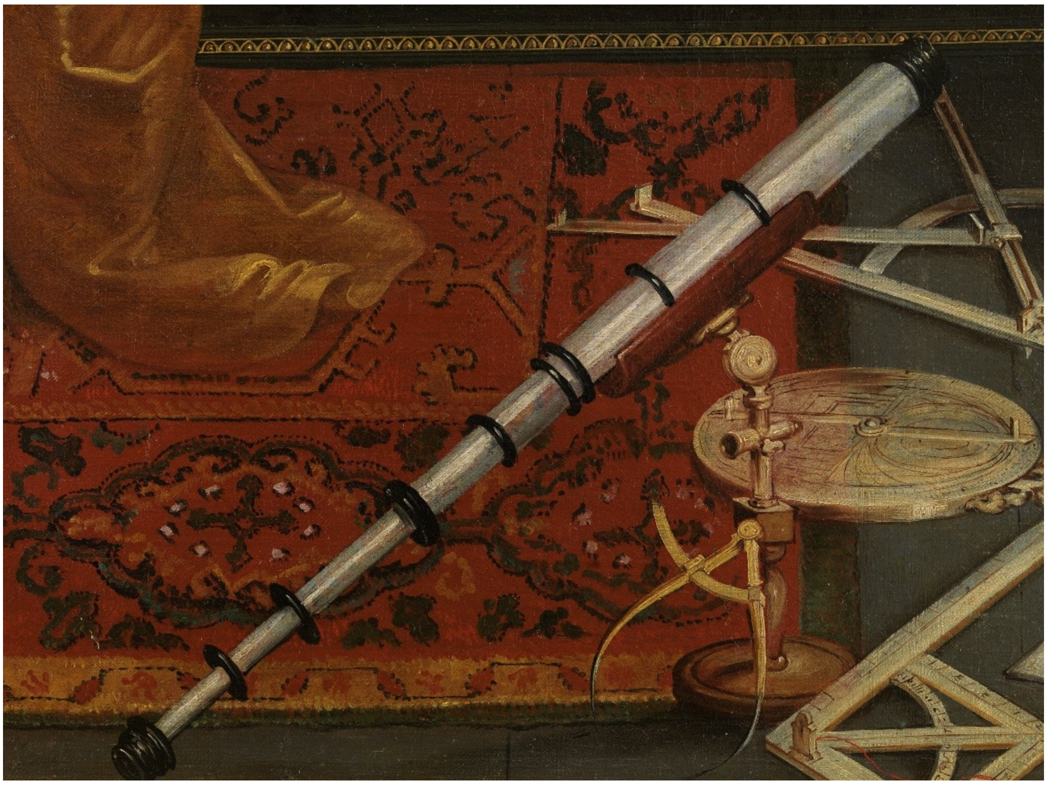
Figure 9

Pieter Paul Rubens and Jan Brueghel the Elder, The Sense of Sight, 1617, oil on wood, 64.7 x 1095 cm. Madrid, Museo Nacional del Prado, inv. n. P01394.

The allegorical series dedicated to the senses performed by different painters were intended to represent every object in the world as a function of the senses required to know it and a reflection to classify and understand the physical world at the beginnings of science. Among the scientific objects disseminated around the picture, a sophisticated telescope in size and shape can be observed in the foreground. In addition, a monkey holds a second telescope, much simpler than the former (a simple smooth metal tube, lacking decoration and rings, with its lenses at the ends). The variety of designs shows evidence of the improvement of the manufacturing technology of telescopes in just a few years, yet it may suggest some questions (i.e. how was a presumably Keplerian telescope painted in 1617?), prompting the idea that art may also serve as a qualified witness to highlight the importance of the controversies in science, which students might discover in their observation or in their search for information, which, in turn, might trigger incentive, motivation, and interest.

The second artwork is part of the allegorical series, *The Five Senses,* at the Prado Museum, and includes two canvases dedicated to *The Senses of Sight and Smell* and *The Senses of Taste, Hearing and Touch*. Both paintings are replicas (made around 1620) of the canvases originally commissioned by the Archdukes Alberto and Isabel Clara Eugenia in 1617 to the twelve best painters in Antwerp, who decorated the Palace of Coudenberg (Brussels) as the fire destroyed the original paintings in 1731 (Díaz Padrón & Royo-Villanova, 1992). Again, *The Senses of Sight and Smell* (Figure 10) depicts numerous optical and measurement instruments, where a very large telescope on an articulated stand – similar to that in figure 9 – is central to the composition, where a compass, an astrolabe and various stacked books (a treatise of cosmography, etc.) are also portrayed; on the top of the books rests a simpler telescope, without any decoration.

Figure 10
Detail of Jan Brueghel the Elder, Hendrick van Balen, Gerard Seghers (and others), The Senses of Sight and Smell, oil on canvas, ca. 1620, 176 x 264 cm. Madrid, Museo Nacional del Prado (P01403).



In later decades, these cabinet paintings and the theme of sight would become very popular in the south of the Netherlands, and we can find numerous examples that reproduce the models painted by Brueghel and Rubens in *The Sense of Sight* (1617) or in *The Senses of Sight and Smell* (ca. 1620), with slight variations. Regarding the present issue, the interesting thing is that the presence of the telescope in the cabinet paintings became a constant, and artists belonging to the next generation, like Jan Brueghel the Younger (Antwerp, 1601-1678) or Jan van Kessel I (Antwerp, 1626-1679), included telescopes almost systematically in their compositions, together with compasses and astronomical quadrants, etc., which offer a visual testimony of the rapid assimilation and dissemination of these scientific novelties to understand the visible world beyond the limits of our eyes, as well as witnessing their technical evolution. Another artistic test of the rapid dissemination of Galileo's findings reported in *Sidereus Nuncius* across Italy and Europe is also found in some artworks of the period. For example, *The Assumption of the Virgin,* by Ludovico Cardi da Cigoli, presents the Virgin Mary standing on a moon in its waxing fourth quarter, half crushed and filled with craters, reflecting Galileo's observations (Figure 11). As Bucciantini et al. (2012) demonstrate, a note written by Sigismondo Coccapani – one of Cigoli’s collaborators – testifies that Galileo himself took part in the pictorial project design. In *Divine Wisdom* by Andrea Sacchi, the earth is represented away from the sun, which occupies the center of the artwork, symbolizing that the earth is no longer the center of the orb, but instead revolves around the Sun (Figure 12). In particular, this last work was painted around the time of Galileo's conviction by the Inquisition (1633), and may be a relevant indicator of the popularity that his heliocentric findings and ideas had achieved.

Figure 11
Ludovico Cardi da Cigoli, The Assumption of the Virgin, 1612, fresco, Rome, Santa Maria Maggiore, cappella Borghese (detail of the Moon).

Pedagogical Development

The previous sections display several contributions of science and art to the objective of HoS for the case of Galileo and the telescope. The historical data discussed above show the temporal and conceptual relationships among science and art so that some guidelines for teachers and SE researchers for the development of an interdisciplinary teaching and learning sequence (TLS) focused on the telescope, Galileo and the corresponding artworks proposed as the didactic consequence to teach science and HoS through art. The guidelines are general enough to embrace different educational levels. Thus, the expectation is that teachers can choose and appropriate some of the suggested ideas and activities to develop their own tailored TLS for their specific learners, according to students' level, subject, and curriculum. Throughout the article, the relationships of science and art have been pointed out through sharing the same historical time, so that the history involved in artworks is the core innovation that scaffolds history of science for teaching science. For instance, Cigoli's painting (art) shows science (moon craters) and the relationships among the artist, the scientists and the telescope (history).

Figure 12
Andrea Sacchi, Divine Wisdom, 1629-1631, fresco, 13 x 14 m. Rome, Galleria Nazionale di Arte Antica, Palazzo Barberini, with the Sun in the centre and the Earth revolving around it.

Overall, the science content of the TLS is the human vision, the optics of telescope, Galileo's astronomical discoveries, and the issues of nature of science and technology involved in the history of these contents. Obviously science and technology are the main school subjects to frame this content, but also general history and history of art subjects may be considered. Thus, teachers must develop their own TLS by selecting the content whose infusion in their teaching subjects better fit and enhance their lessons. Accordingly, beyond the science background content on vision, optics or astronomy, some historical-social-philosophical-artistic goals are stressed: the comprehension of the relation between science and technology; the multiple social and cultural interactions of science, especially with the arts; and the epistemological importance of observation in science and arts (Vázquez-Alonso, & Manassero-Mas, 2013).

The pedagogical proposal applies the 7Es model (Eisenkraft, 2003) to structure the basic ideas of this science-art interdisciplinary TLS, through their seven stages that begin with E (Extract-Elicit, Engage, Explore, Explain, Elaborate, Extend and Evaluate). For each stage, some learning activities to be carried out in the classroom, the teaching materials to be used, and the learning products that are expected to be elaborated on by students, either individually or cooperatively (through small or whole-class group work), are depicted. The sequence of the stages and activities as presented below does propose a specific prescription for practice; instead, teachers are free to go forward or backward on their own through the stages for the best development of the TLS. All in all, a gradual methodology in the activities, combining individual work, discussion, and synthesis activities in small or whole-class groups are suggested, leaving room for teachers to set up required details.

Stage Extract-Elicit

This stage aims to elicit students' previous conceptions in order to diagnose their learning needs in the next stages. Therefore, the main activity of this stage will be asking students about their conceptions and previous ideas on the TLS issues. Some examples of questions are the following: What experiences have you had with telescopes or spyglasses? What is a telescope? Can you guess how it works? Do you know the date and name of the telescope’s inventor? What about Galileo? What are your reasons to support that the sun goes around the earth? What else do you know / have experienced about that?

Teachers should encourage students to seek good evidence and reasons to justify their answers; for example, they should collect drawings and images of ancient optical telescopes in books, comics, films, videos, make use of home binoculars, spyglasses, and the like. Teachers might find inspiration and complement students’ evidence with some information from Sections 2, 3, 4 and 5 of this paper.

At the end of this stage, the teacher should have a clear understanding of students’ previous conceptions and experiences. Some expected products of this stage are the following: a list of prior ideas about the use and working of telescopes; a list of evidence provided by students; and a list of pending or new questions raised during the stage as the basis for students’ motivation and interest in finding reasonable answers to the questions.

Stage Engage

This stage aims to motivate students, arousing their interest and curiosity, taking into account their diverse backgrounds and previous experiences. The presentation of some selected artworks from students' ideas and teachers' plans has a central role in this stage in order to start historical bridge-building between art content and science subjects; teachers should carefully select the artwork, according to their lesson plans and the results of the previous stage on students' prior ideas.

The main activities would be centered on detailed observation of the content of the paintings shown here or additional ones sought by students, elaborating their technical cards, searching for additional information on the Web (or adding another artwork) or any other similar activities. The artwork observation for discovering details is similar to both a game and scientific task, so it likely provides a rewarding potential for students' interest and motivation on the issue.

Stage Explore

This is the key stage for basic learning, as it aims to advance comprehension through activities, which involve designing projects or experiments, solving problems, collecting and analyzing data, extracting conclusions, developing hypotheses, making predictions, and discussing topics, etc., according to the school science curriculum. Students read critically some historical texts and are asked for clarification of details, for confirmation through information or observation of the astronomy facts the texts referred to--for comprehension of the whole text, the understanding of the Aristotelian and Ptolemaic contexts of the historical worldview in the 17th century, and understanding human vision, optical telescopes (analysis of their structure, application to observations of distant objects, and optical laws, etc.).

As a result of the readings, students should develop a personal summary of the text and historical context. Then, students may cope with a problem-solving task: construction of a simple telescope through cooperative group work where the teachers help by supplying materials and guide practical operations of groups. The task may evolve from simple playing with two appropriate lenses to observe the magnification of distant objects, for younger students, to complex experiences with hypothesis and exact measurements of the observations and placement of lenses for higher grades. The teachers select from the texts according to the specific problem solving task, either drawn from some of the paper references or their own experience.

Stage Explain

This stage consolidates learning as it aims to interpret and reinforce the results of the exploration phase, by using science and art concepts, terminology, facts, laws, etc. The students try to observe through their telescopes or domestic spyglasses one astronomical event like the Moon related to Galileo's activities in order to explain and deepen their own experience and understanding. Further, the students try to relate the cards of the pictures (elaborated at the *stage engage*) with some of Galileo's activities, giving special attention to facts, dates, and references to the telescopes represented in artworks; also, students may seek additional information in books, journals and online resources to clarify the differences between Galileo's and others' interpretations of observation like Scheiner's controversy.

Working in small cooperative groups, the students can prepare a group report that organizes and structures all the relevant information gathered in the previous activities. The report must give special attention to clarify the controversial impacts of Galileo's contributions within the historical context of his time.

Stage Elaborate

This is the stage for significant learning, as it aims to transfer and apply learning to the current environment ask new questions, or pose new problems. Since the TLS is centered on the history of science and art, the underlying issue of this stage are the lessons of past history for the present. Thus, the students are asked questions that try to project the knowledge and the advances produced in Galileo's time toward the present. For instance, what method did Galileo use to make his ideas successful? What advantages and disadvantages does the method have? What about the social life of Galileo? What about Galileo's relationships with authorities, artists or important people? What about the reason(s) leading Galileo to advocate the heliocentric model? What about the validity of Galileo's method today?

The expected final product is a student's reflection paper that must be aligned with the selected specific activities previously developed by students. The teacher should administer the questions and orient the students' answers to the questions and the free elaboration of the reflection paper, which may include, but are not limited to, the following items: a summary of Galileo's observational method or interpretations, a list of its advantages and disadvantages, a highlight of the relationship between Galileo and artists, authorities, colleagues and others, and pro and con reasons for the heliocentric model, etc.

Stage Extend

This stage aims to excellence in learning by developing creativity to transfer and apply learning to new domains, issues and contexts. Again, students are stimulated by advanced questions that try to project the knowledge beyond the classroom curricula. For instance, what consequences did Galileo's telescope have on science and on daily life? What consequences would Galileo's methods have on daily life and on school life if they were applied? What do you think about the role of the creativity and imagination in Galileo's labor, artworks and science? Can you think about some sociocultural, political, economic, etc., factors that influenced Galileo's work? Can you seek social organizations that helped telescope development and Galileo's findings? Can you find some answers to the questions in the artworks of the time?

Further, a factory visit might provide students a closer view of updated applications of some industries related to Galileo's and other artists' activities. For instance, a visit to an optician may contribute to students’ understanding of the instruments and measurements to enhance human vision. Other worthwhile visits would include:

1) Glass industrial factory to know about glass recycling, raw materials, polishing, and transparency techniques, etc.
2) Commercial business of optic instruments to make students aware of the high quality of optics for current cameras or telescopes.
3) Manufacturer of painting chemicals to promote students’ learning about colors and mixtures.
4) Museum to allow students to search for the presence of science and technology in their artworks.

The outcome of this stage is a personal reflection that must relate the question selected to the visit and may be left to student’s creativity and interest on the issues at work. For instance, students may write and explain a problem/consequence that could be easily solved with Galileo's method and their reasoned solution; advantages and disadvantages of creativity and imagination in science and art; analysis of the manufacturing factors and the social organizations that influenced telescope and Galileo’s success. In Galileo’s case, the reflection framework here may include some aspects of the NoS, such as global change, the scientific controversy, social and institutional interaction, and the progress in science and technology (Erduran & Dagher, 2014; Rudge & Howe, 2009).

Stage Evaluate

This stage aims to judge students’ learning achievements by applying formative assessment methods and instruments to evaluate all aspects of learning. Overall, all products of learning prepared by students during lessons are the first raw evidence to judge learning; in particular, the technical cards of paintings, the problem solving task, the group report, the student’s reflection paper, and the comparison between the question selected and the visit should be assessed. Further, teachers are encouraged to elaborate specific rubrics to assess any other products of learning whose internal assessment criteria take into account the main content and orientations suggested by the TLS, for instance, the students’ conceptions of NoS, the integration between history of science and art, and the appreciation of art as a trail to science.

Depending on the curricula development and grade, this teaching-learning sequence could be infused especially in science and technology subjects, whose curricula promote and develop much in-depth of the aforementioned issues and allow the involvement of art and history subjects. Further, pre-college students from grades 9 to 12 might fit better the conditions and features of the proposal. For instance, the Spanish national curricula for these grades include explicit and wide references to Galileo, the telescope, the heliocentric model and the scientific revolution and the art, competences to understand scientific research, use of ICT to seek and communicate information, evaluation of ideas about the NoS and technology on daily life issues, and cooperative work (Ministerio de Educación, Cultura y Deporte, 2014).

The Next Generation Science Standards (NGSS, 2013) of the USA set up an explicit connection between the arts and science for the sake of coherence. Each set of performance expectations provides connections to science and engineering practices and to Common Core state standards in English language, arts/literacy and mathematics, which are justified by the opportunity for science to be a part of children’s comprehensive education. Specifically, the Copernican Revolution is mentioned as a case study to instruct children to help them understand a core aspect of NoS, that is, the change of scientific knowledge.

Finally, the proposal is deliberately broad and general[4] so that it can be adapted to the specific curricular needs or even to lower grades six to nine. It should be stressed that in any case, teachers would put into practice the entire set of tasks or follow the order above. As a rule, it is suggested that activities involving students’ cooperation, reflection and discussion should be designed to be completed within the same lesson period, approximately one hour.

Final Remarks

The telescope is an emblem of the birth of modern science and a technological tool whose early development is still little known, to the point that its invention has no date or inventor. This transgression of the usual stereotype of inventions makes it an attractive and challenging motivational target of interest for students, which in turn illustrates the social nature of discoveries and inventions, beyond eponymy.

From the scientific perspective, the telescope through art offers a simple and comprehensible historical example that triggers philosophical, sociological and technological aspects of science as a human and social enterprise. For instance, the history and artworks on the telescope highlight the relationships between S&T, the current deep integration between the scientific instrumentation applied to achieve knowledge, and the knowledge produced so that this incipient imbrication of S&T has currently led to the term techno-science.

Further, the history of Galileo's telescope raises several issues that are crucial to teach philosophy (change of scientific knowledge), sociology (collaboration and competence among scientists; struggle for eponymy), and the NoS and technology in SE (technological instrumentation for enlarging knowledge), which are also supported by the didactical use of artworks (moon craters, Milky Way) and reflected in some activities from the teaching-learning sequence (cards of artworks, problem solving task, personal reflection).

First, the use of the technology to expand scientific knowledge must be noted. By means of his telescope, Galileo could perceive details nobody could have seen at a glance: he could see, for example, moon craters and clusters of stars imperceptible to the eye. Then, he could

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[4] The teaching-learning sequence does not contain systematic methodological specifications; teachers are encouraged to adapt and make their own decisions. However, let us note that the methodological traits mentioned in the theoretical framework (explicit teaching, centred on students’ reflections and developmental adaptation) should be compulsory methodological guidelines for teaching.

discern that the great diffuse belt of the Milky Way was really made up of thousands of stars grouped into star clusters. The painter Adam Elsheimer (Frankfurt am Mein, 1578 – Rome, 1610), closely linked to the Accademia dei Lincei, reflected this and other findings of Galileo in his paintings at an almost contemporaneous moment (Figure 13).

Figure 13
Adam Elsheimer, The flight into Egypt, 1609, oil on copper 31 x 41 cm, Munich, Alte Pinakothek[5]*.*

Another interesting aspect of Galileo's life is the dispute over the priority of the discoveries that illustrated the current hard competition among scientists. The discovery of sunspots and Jupiter moons and the priority for eponymy of the latter have already been mentioned.

Further important epistemological matter derived from Galileo's use of the telescope is, one of the cornerstones of science, the replication and confirmation of findings by different and independent scientists. As the construction of telescopes at the beginning of the 17th century flourished in Europe, astronomers from different places could replicate and confirm (or disconfirm) the observations on sunspots or the moons of Jupiter. This replication power constitutes a major heritage, which, in Galileo's time, influenced some contemporary artworks, and today has also produced educational replications for SE (Kubli, 1999).

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[5] Let us note the representation of the Milky Way stars as sharply individualized entities, and the detailed surface of the moon.

Galileo's observations generated counter-examples and counter-arguments incompatible with the geocentric Aristotelian and Ptolemaic system, and therefore, they started a major scientific controversy, that is, an epistemological dispute between two scientific theories on their validity through hypothetical deductive reasoning based on empirical evidence (Lawson, 2002). The enormous resistance throughout the 17th century to accept that the earth was not the center of the universe, in spite of Galileo's proofs, constitutes a paradigmatic example of the complexity of the epistemological closure processes for a controversy (replacement of scientific theories). Galileo's telescope also provides a paradigmatic example of technology applied as scientific instrumentation to improve scientific knowledge and, at the same time, is an example of applied science by means of using early optical scientific principles to improve the telescope. According to Pacey (1983), any technology requires a complex support system with three related dimensions--technical, organizational and cultural. These three dimensions are also obvious in the development and application of the telescope. Galileo provided the technical dimension with his personal artisanal skills, but he needed external organizations, such as the glass industry to produce quality lenses or the protectors who provided economic support, and cultural organizational institutions like the Accademia dei Lincei, as supportive and critical peers to attain the spectacular scientific, ideological and cultural impact, which decisively contributed to radically change mankind's worldviews.

In addition, the association of the telescope with its representations in contemporary works of art constitutes an earlier example of integration among science, culture and society, which still is paradoxical today, given the usual disciplinary separation between school subjects like science and art. Therefore, the interdisciplinary lesson between HoS and artworks and the relationships among knowledge, science, technology, society, and culture provided by the telescope can be an exciting and motivating feature for students.

In sum, Galileo's telescope provided for the illumination of a new worldview, whose pedagogical, communicative tool was embodied by artworks that transferred to and impacted people. Thus, art was the communication and information tool of science knowledge to people of the time, inasmuch as the current integration of science and art may represent an educational and motivating tool for learners in school science. Furthermore, given the themes of art representation mentioned here--several pictures are titled allegory or sense of sight--a natural future extension of this research joining art and science could cope with the history of medicine. Medicine has been not only an overall pervasive scientific and technological activity in all cultures and all societies along centuries, but also has been widely depicted in artworks.

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