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Pupils Produce their Own Narratives Inspired by the History of Science: Animation Movies Concerning the Geocentric–Heliocentric Debate

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Abstract In this paper, we present the design and application of a teaching scenario appropriate for 12-years-old pupils in the primary school aiming to a better understanding of scientific concepts and scientific methods, linking the development of individual thinking with the development of scientific ideas and facilitating a better understanding of the nature of science. The design of the instructional material supporting this scenario has been based on the study of the history of astronomy and especially on: (a) The various theories concerning the movement of Earth, our solar system and the universe. (b) Key-stories highlighting the evolutionary character of scientific knowledge as well as the cultural interrelations of science and society. The design of the teaching scenario has focused on the participation of pupils in gradually evolving discourses and practices encouraging an appreciation of aspects of the nature of science (e.g. the role of observation and hypothesis, the use of evidence, the creation and modification of models). In this case, pupils are asked to produce their own narratives: animation movies concerning the geocentric–heliocentric debate inspired by the history of science, as the animation technique presents strong expressional potential and currently has many applications in the field of educational multimedia. The research design of this current case study has been based on the SHINE research model, while data coming from pupils' animation movies, questionnaires, interviews, worksheets, story-boards and drawings have been studied and analyzed using the GNOSIS research model. Elaborated data coming from our analysis approach reveal the appearance, transformation and evolution of aspects of nature of science appreciated by pupils and presented in their movies. Data analysis shows that during the application pupils gradually consider more and more the existence of multiple answers in scientific questions, appreciate the effect of culture on the way science functions and the way scientists work as well as the effect of new scientific interpretations that replace the old ones in the light of new evidence. The development of pupils' animation movies carrying aspects of the history of astronomy with a strong focus on the understanding of the nature of science creates a dynamic educational environment that facilitates pupils'

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introduction to a demanding teaching content (e.g. planet, model, retrograde motion) placing it in context (key-stories from the history of science) and at the same time offers to pupils the opportunity to engage their personal habits, interests and hobbies in the development of their science movies.

1 Teaching Strategies for Using History of Science in Science Education

Current research in science education emphasizes more and more on the use of history of science in science teaching.[1] In most of these research and development attempts, history of science is elaborated for the classroom in the context of philosophy of science, highlighting a more desirable picture of the nature of science and its importance in science teaching.

History and philosophy of science when incorporated in science teaching contributes in promoting a better understanding of scientific concepts and scientific methods, linking the development of individual thinking with the development of scientific ideas and facilitating a better understanding of the nature of science (Matthews 1994). The demand now is to develop functional teaching strategies for using history and philosophy of science in science education. Some of the recorded teaching approaches in this context are the following:

- the "story-line" approach (Stinner et al. 2003; Hadzigeorgiou 2006)
- the "case study" approach[2]
- the recreation of historical instruments (replicas) and historical experiments (Heering 1994; Reiss 1995),
- the use of role-plays (Stinner et al. 2003; Seroglou et al. 2008),
- the presentation of portraits of historical characters and historical vignettes (Aduriz-Bravo 2005; Koliopoulos et al. 2007),
- the discussion of social and ethical aspects of science (Hagen et al. 1996),
- the use of computer simulations of historical experiments (Masson and Vázquez-Abad 2006)
- the recreation of historical debates (Solomon et al. 1992),
- the elaboration of historical thought experiments (Klassen 2006; Galili 2009),
- poster design and poster presentation concerning cases from the history of science (http://www.atlaswiki.com/page/science+teacher+etraining(stet), http://www.stet.wetpaint.com),
- group discussion on historical texts (http://www.atlaswiki.com/page/free+fall, http://ppp.unipv.it/map),
- web-site design for the use of instructional material and activities of the classroom inspired by the history of science (http://www.atlaswiki.wetpaint.com, http://www.stet.wetpaint.com, http://www.ppp.unipv.it/map, http://www.hipst.eled.auth.gr).

This variety of approaches shows the multi-dynamic effect of the use of history of science in science teaching as well as the strong influence that the study of the history of science may have on researchers coming from a variety of fields (science education, history

[1] On this point see (Duschl 1994; Matthews 1994; Stinner et al. 2003; Seroglou et al. 1998; Seroglou and Koumaras 2001; Matthews et al. 2001; Osborne et al. 2003; McComas et al. 1998; Lederman 2007).

[2] On this point (see Irwin 2000; Stinner et al. 2003; Bevilaqua and Giannetto 1998).

of science, philosophy of science, information and communication technologies in education, art studies, social studies etc.). History of science seems to inspire all these researchers with different backgrounds and as a result an ongoing production of teaching material and activities for the classroom is taking place.

In most of the above cases, researchers and educators use forms of an audiovisual language (films, videos, narratives etc.) and transform those into instructional material. This instructional material is either selected from the rich variety of the international audiovisual production (films, science fiction movies, documentaries, cartoons etc.) in terms that they serve the pre-defined teaching and learning aims or this instructional material (short movies, videos etc.) is developed especially for the science classroom and carries and realises the teaching and learning aims in its design.

In our case, we implemented and assessed the use of a teaching tool coming from media and video studies: animation movies inspired by the history of science. Young pupils attending the sixth grade of a Greek state school (12-year-olds) presented, narrated, dramatized, compared and commented in their own way the evolution of theories and models that have been developed concerning the geocentric-heliocentric debate from antiquity till renaissance. Pupils finally developed short animation movies using a variety of expressional means. In our case, the teaching and learning aims were active in the learning environment developed by the researchers and the teachers involved. In the context of this learning environment, pupils themselves developed audiovisual material expressing their interpretations and comments concerning the rise and evolution of theories about the movement of the Earth, the Sun, the planets and the universe. This is the key-difference between our case and the previously mentioned ones: audiovisual narratives inspired by the history of science are not only used as instructional material reinforcing science teaching, but are developed in a learning environment by the learners themselves and express learning pathways towards the acquisition of knowledge.

Our approach lies in agreement with current educational research trends supporting that narratives may not only be used as vehicles in the process of education but also as modes of thinking and as structures for organising knowledge (Bruner 2004; Lemke 2002). In our case, pupils develop short movies (audiovisual narratives) presenting their thinking patterns and concept structures concerning the theories around the geocentric-heliocentric debate.

Furthermore, during the last 25 years, science education is shifting from the monopoly of verbally based modes of instruction to teaching approaches informed with multiple representations. Researchers strongly support that meaningful learning occurs when learners construct and coordinate multiple representations of the same material including visual and verbal representations. Our approach, inspired by the dual coding theory, encourages pupils to select words and images, organise them in texts and sets of images or moving pictures and build referential connections between them in the context of animation narratives.[3] However, in our case, pupils also select a variety of representations such as music, sounds, videotaped role-plays etc., in order to organise and correlate them to the science content presented in their narratives.

[3] On this point (see Houghton and Willows 1987; Willows and Houghton 1987; Mandl and Levin 1989; Paivio 1986; Clark and Pavio 1991; Mayer and Anderson 1991, 1992; Mayer 1997; Lemke 1998; Kress et al. 2001).

2 Pupils Develop their Own Animation Movies: Expectations and Perspectives

Animation as an instructional tool carries strong expressive features and produces impressive representations. That's why animation has been considered as one of the key tools for creating educational multimedia (Boyle 1997). Animation is defined as a sequence created picture by picture, or "frame by frame" using film terminology. Animation is a series of still images. The creation of each picture (or frame) can be done with various ways and materials (Halas and Manvell 1969; Laybourne 1998). Each picture could present drawings, objects or people in various positions. When all these still pictures are put in a sequence and are presented successively, then a stream of unbroken moving pictures is produced.

An animation may consist either of a series of drawings or photographs on paper. There are two ways to see an animation: using a mechanical device (computer, video etc.) or with a flip-book (flipping through hand-held sequences of images). In order to create an animation, the procedure presented in Fig. 1 has to be followed. First, the key-idea on the subject to be elaborated is developed. Then, the script is written and the visuals to be used in the creation of the still pictures are designed. After this phase, the original script undergoes through treatment in order to have the story board. At this point, the models and the sets to be used in the movie have to be prepared. Then, the dialogues are recorded and included in the movie and the first animation sequence is edited. When the sound is recorded, then the timing is worked out. Sounds, images, dialogues and ideas to be presented have to be synchronized. The shooting takes place (models and set must be ready by that time). The final movie is edited and remains only sound dubbing and some refinements for the final production.

The introduction of animation in the educational process and especially the involvement of the pupils in order to produce their own animation movies may assist in achieving objectives concerning not only the learning of the content, but also the development of skills.

The engagement of pupils in developing their own animation movies in order to be fruitful has to carry the following characteristics:

(a) Simple everyday materials such as clay, paper, cloth, photos, small objects, etc. available at every school may be used to create the models and sets for the shooting.
(b) Computers, cameras, sound recorders, media/movie maker software available in most schools has to be used to create simple animations.

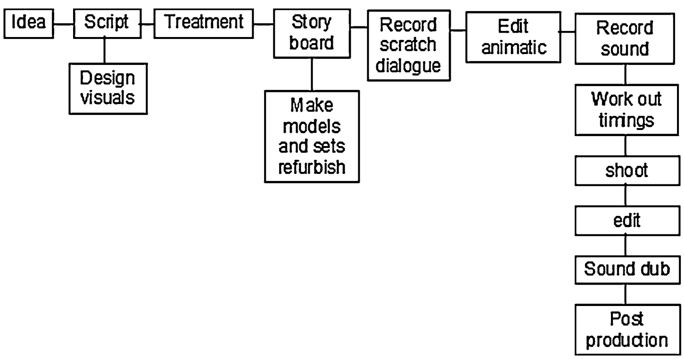

Fig. 1 Elements of an animation shoot (Shaw 2004)

(c) Experimentation and exploration in the audiovisual language has to be encouraged (with a minimum cost available to any amateur who wants to create a movie).
(d) Animation movies should give space to pupils' creativity: Pupils can choose to animate objects, their own drawings, their own body or even figures they have cut out and these are only some of a big variety of ideas for the form of the materials to be shot. They may use texts, images, theatre practices individually or a combination of them. Pupils also decide on what kind of sounds they will have in their movies (dialogues, music, sounds from nature or from an industrial environment, audio descriptions using their own voices etc).
(e) Pupils should have the opportunity to compare different solutions on the movie making problems they face, to choose the most suitable and make decisions in order to represent the learning content in a communicative way.

Using animations in the classroom, such an expressional, engaging and flexible learning tool, teachers gain a "window" into their students' understanding. In their movies pupils represent didactical transformations of the teaching content that are familiar and make sense to them and could also become useful instructional material. The development of animation movies in classroom may be considered as a form of a collaborative inquiry process, where various expressive means are combined in order to produce a movie. Pupils express their ideas, use their expertise, develop new skills, coordinate and synthesize their sound and image products. At the same time, they understand better and become familiar to concepts, procedures and skills related to the topic of the produced film. In our case, pupils work together in order to analyze and process information concerning the evolution of scientific theories about astronomical models in the history of the science, choose narrative techniques to combine the developed material and produce their movies, while being introduced to the audiovisual language.

3 Research Design and Methodology

Our research design has been based on the SHINE research model (Seroglou and Koumaras 1999, 2001, 2003). The name SHINE is an acronym of the key-words "Science", "History", "Interaction" and "Education". The SHINE research model consists of eight stages realising the interplay between history of science and science education in the context of instructional development and evaluation (Fig. 2).

The eight steps of SHINE are the following:

Step 1: Research on scientists' ideas in the history of science is carried out. Research is focused on those areas where early scientific ideas were different from the currently accepted ones.
Step 2: Data coming from the history of science provide a focus for the research on learners' ideas.
Step 3: Research on learners' ideas about science and the nature of science is carried out (questionnaire distribution, individual in-depth interviews and/or study of contemporary relevant bibliography).
Step 4: A comparative analysis of data and results coming from research Steps 1 and 3 provides an answer to whether research into the history of science (and especially in those areas where early scientific ideas were distinct from current ones) indicates a clear focus for the research on learners' ideas.

History of Science	*Interaction field*	*Science Education*
1. Research on scientists' ideas	**2.** Research focus	**3.** Research on students' ideas
	4. Comparative analysis	
5. Research on the work of scientists that promoted the change of scientific ideas	**6.** Instructional material design (activities inspired by the history of science)	**7.** Research on the evaluation of the designed tasks in promoting learning
	8. Comparative analysis	

Fig. 2 The SHINE research model

Step 5: Research on the work of scientists that promoted the change of scientific ideas and led to the currently accepted ones (as presented in textbooks) is carried out.

Step 6: Data coming from Step 5 provides fruitful information for instructional material design and leads to the design of a set of activities.

Step 7: Research on the evaluation of the designed activities in promoting learning is carried out (questionnaire distribution, analysis of worksheets and videotaped data).

Step 8: Finally, a comparative analysis of data and results coming from research Steps 7 and 5 provides an answer whether certain activities inspired by the work of scientists in the past (that promoted the change of scientific ideas in the history of science) help learning and encourage nature of science understanding.

In the current paper we present a SHINE case study in mechanics and especially on the geocentric- heliocentric debate. In our case the eight SHINE steps are the following:

3.1 Step 1: Scientists' Ideas About the Earth, the Solar System and the Universe

We studied in the history of science the various theories concerning the movement of Earth, our solar system and the universe (for example the theories of Aristotle, Aristarchus, Ptolemy, Copernicus, Brahe, Galileo, Kepler). The astronomical models that prevailed in the different phases of the history of science, as well the cultural, social and ideological dimensions that contributed in the configuration of every system are important resources of knowledge for the ways that human thought has evolved about the universe (Halkia 2006).

Although we thoroughly studied many episodes from the history of science, we finally selected to use in this case, those episodes that bring forward for discussion with the pupils nature of science aspects concerning: (a) the role of observation, (b) the architecture of hypothesis, (c) the explanatory potential of models, (d) the influence of technology on redefining observation, (e) the theory network that supports and is supported by scientific models (a new model could break or reshape the matrix of theories) and (f) the influence of society (e.g. culture, religion, politics) on model construction and its dissemination. Therefore, certain episodes have been selected from the history of science like the ones presented below.

The ancient greek philosophers and astronomers (e.g. Thales, Anaximandros) observed in the sky wandering stars and named them "planets" as planet in greek means something or someone that is moving, travelling in space, wandering around (Dicks 1970). This episode provides the background to discuss with pupils the role of observation.

Philolaus (ca. 470–ca. 385 B.C.) describes a system of celestial bodies (including the Earth, the sun and the planets) that move in orbits around an everlasting fire that lies in the centre of this cosmos (Lloyd 1970; Paleopoulou-Stathopoulou and Koukopoulou-Arnellou 1999). This episode is an example for the pupils of the development of a hypothesis.

Plato (ca. 428–ca. 348 B.C.) supports that the observations of planets in the sky should be informed with mathematics and geometry in order to produce explanations of planetary movements (Dicks 1970; Crowe 2001). In this episode, pupils have the opportunity to discuss the interaction of different fields of knowledge, in this case mathematics and science.

Eudoxus (ca. 400–ca. 347 B.C.) suggested again an Earth-centred cosmos with a solution to the problem of retrograde motion of the planets using the theory of interconnecting spheres (Duhem 1969; Paleopoulou-Stathopoulou and Koukopoulou-Arnellou 1999). This episode is an example of the introduction of a new model.

In the third century (384–322 B.C.), Aristotle supported the geocentric model and elaborated it with 55 perfect and unchanging spheres (Duhem 1969; Dicks 1970). With this episode, pupils discuss about the modification of models.

Aristarchus (ca. 310–ca. 230 B.C.) gave a different perspective of the place of the Earth in the universe: he proposed that the Earth is moving around the sun. Aristarchus was influenced by Irakleidis' ideas concerning a rotating Earth and by post-Pythagoras thinkers' hypothesis suggesting that the Earth moves around an everlasting fire (Heath 1913/1981). Aristarchus proposal was not accepted by the social milieu of his era as the model of Aristotle was strongly adapted as part of the contemporary worldview (Paleopoulou-Stathopoulou and Koukopoulou-Arnellou 1999). In this episode, pupils have the opportunity to discuss about: (a) the introduction of a new hypothesis, (b) the role of the cultural and theological background of the scientist on the construction of his theory and (c) the science-society interrelations.

In about 230 BC, Apollonius (ca. 240–ca. 190 B.C.) offered a new explanation for the retrograde motion with epicycles (a greek word meaning "circles within circles") (Crowe 2001).This episode provides material for pupils to discuss about the influence of observation on models and how new observations may lead to new models or to the modification of old ones.

Ptolemy (ca. 100–ca. 170 A.D.) refined the "epicycles" model, suggested that the Earth was not quite in the centre of the universe and that the planets moved around a point near the Earth called the "eccentric" (Ptolemy 1984). Ptolemy's model was accepted for 1,000 years as the best way to describe the motion of heavenly bodies, e.g. eclipses and other astronomical phenomena occurred reasonably close to when they were expected. However, Ptolemy's theory had to survive the Aristotelian model that was highly appreciated by the church and the astronomers' reports on recording its predictability problems (Repcheck 2007). This episode is an example of the observations-model interplay: new observation and evolutions in mathematics lead to the elaboration of models.

In the early sixteenth century, Copernicus (1473–1543 A.D.) worked on the problem of the movement of the planets and of retrograde motion and created a set of axioms and formula describing the movement of the Earth around the sun (Copernicus 1543/1995). Copernicus using mathematics claimed that the planets (including the Earth) were rotating around the sun. Although, Copernicus remained faithful to the axiom of circularity and uniformity of celestial motions and he had to adopt intricate combinations of circles which made his system technically no less complex than the Ptolemaic system, he provided a model that supported an ultimate demonstration of the perfect harmony of the cosmos with six planets all continuously revolving in the same direction around the Sun (Copernicus 1543/1995). However, a period followed when the geocentric and the heliocentric models were both functional enough in predicting the motions of the Earth and the planets. This episode may help pupils appreciate that many scientific explanations are based on models (and their mathematics) which may involve things that cannot be directly observed.

In the sixteenth century Tycho Brahe (1546–1601 A.D.) made observations and accurate estimations of the positions of the planets for nearly 20 years. Tycho Brache tried to combine the outcomes of his observations with his deep belief of Earth's absolute immobility (Crowe 2001). Two key-observations of Tycho Brache showed that the crystal spheres were neither perfect nor unchanging and eternal: he recorded a supernova (in 1572) and a comet which went through the crystal spheres of the Ptolemaic model. Brahe created a model presenting the planets moving around the sun and at the same time, this system (the planets and the sun) as a whole rotating around the Earth (in this model the Earth remains still and is the ultimate centre of all). This episode is a chance to discuss with pupils the attempt of the scientist to combine the data coming from observation with the social and religious demands in order to form a theory. In this case the lack of a good hypothesis misled the scientist in the interpretation and use of his data coming from observation.

In the years that followed, Johannes Kepler (1571–1630 A.D.) analyzed Brahe's data and found that the orbits of the planets were ellipses and not circles and supported the idea that the Sun is at the centre of the universe and not the Earth (Gingerich 1993). Kepler thought that the heliocentric model made it possible to explain the movement of stars and planets and not just predict their positions. He studied the movement of Mars for 4 years and his studies led him to his three laws of planetary motion, as he was trying to find physical reasons for the planets motion and he supported that some force may extend out from the sun and move the planets in their orbits. Kepler's proposal of an elliptical orbit represented a major break from the tradition of explaining planetary motions by combinations of circular motions (Kepler 1609/1992; Crowe 2001). This episode offers a fruitful background to discuss about the way a scientist's work may be supported by the work of other scientists, but his mathematical or theoretical skills and a promising hypothesis may lead to better interpretations of observations and data and to new models.

After 1610, Galileo (1564–1642 A.D.) made observations of the planets using a first version of a telescope (first telescopes appeared around 1600 in the Netherlands and Galileo is said to manage to get these telescopes, used them and developed more elaborated versions of them). Galileo's observations offered strong counter-evidence to Ptolemy's model. He made observations of the visible imperfections of the Sun and Moon (sunspots, craters), of Jupiter's satellites in different positions of their orbits, and of Venus various positions on its orbit around Sun. Although Galileo did not observe movements, he recorded and drawn "snapshots" of planets (Jubiter's moons, Venus) at different positions on their orbits and the succession of those "snapshots" implied the movement of the planets (Galileo 1610/1989). The moons orbiting around Jupiter confirmed once and for all that not all heavenly bodies revolved around the Earth. When Galileo published his book debating the Copernican and Ptolemaic systems, the Church found him guilty of heresy and sentenced him to house arrest for the rest of his life (Galileo 1632/2001). In 1992, three hundred and fifty years after his death, the Church officially apologized for condemning Galileo and his scientific research. In this episode, pupils have the chance to discuss on the idea that scientific conclusions can be supported by evidence (observation) but not be thoroughly proved; evidence in this case is used in order to falsify the previous model of Ptolemy. Also, pupils have to deal with an episode that shows that new ideas may meet opposition from groups that carry confronting social, political or religious commitments (Matthews 2009).

In the application presented in this paper, the geocentric-heliocentric debate is elaborated in a science classroom of 12-year-olds. Therefore, all the above scientific ideas about the Earth, the Sun and the planets went through didactical transformations in order to be embodied in instructional material and classroom activities that are friendly and easy to understand for this certain age group.

3.2 Step 2: Research Focus

Data coming from the study of history of science in *Step 1* offered us a clear focus for the research on learners' ideas concerning (a) the position and movement of the sun, the Earth and the planets and (b) the nature of science, bringing forwards key-questions and problems to be faced during the teaching of such a course.

3.3 Step 3: Learners' Ideas About (a) the Earth, the Sun and the Stars and b) the Nature of Science

Learners often carry a variety of images concerning the Earth, the sun, our planetary system and the universe in general. Everyday perceptual evidence of a sun rising from the east, moving in the sky during the day and setting in the west and the everyday language that describes this movements with energetic verbs (as if the sun takes action, as if the sun moves) leads many pupils (children as well as adults) to use in their arguments and explanations a geocentric model or sometimes a hybrid model (with geocentric and heliocentric elements blended together). Numerous studies of researchers in science education offer an efficient bibliographical resource that we went through in *Step 3* of our research.[4] The most recent research indicated six main models of the universe held by young students (Liu 2005):

(a) A spinning Earth moves in a universe where the sun, the moon and the planets are immobile and despite its movement, the Earth remains in the centre.
(b) The moon, the sun and the planets are moving in orbits above the Earth, while their orbits and the Earth create a geometric cone with the Earth being on its apex.
(c) The sun, the moon and the planets revolve around the Earth but in most of the cases on a common orbit.
(d) The Earth moves around the sun on a certain orbit, while the sun and the moon are immobile.
(e) The sun is immobile and in the centre, while the Earth and the moon move around the sun on different orbits.
(f) The current scientific model presented in textbooks but with an immobile sun.

In this *Step 3*, we also have to collect previously recorded views about nature of science aspects that affect the elaboration of the geocentric-heliocentric debate and also record the nature of science ideas of the target group. The development of pupils' ideas concerning

[4] On this point (see Klein 1982; Nussbaum and Sharoni-Dagan 1983; Sadler 1987; Jones et al. 1987; Liu 2005).

nature of science has been a concern of science educators for several years.[5] Many of these studies have shown that from kindergarten till grade 12 pupils, as well as teachers, have not acquired the desired understanding of nature of science while pupils' views concerning the nature of science in many cases are not consistent with current accepted definitions of the nature of science.[6] For example pupils:

– appear to carry the notion that many discoveries occur by accident (Ryan and Aikenhead 1992)
– hold an absolutist/empirical perspective of the nature of science (Lederman 1992)
– think that all scientific investigations adhere to an identical set and sequence of steps known as the scientific method (McComas 1996)
– do not recognize the fact that scientists' disciplinary training and commitments as well as their personal experiences, preferences, and philosophical assumptions do influence their work (Akerson et al. 2000).

Research indicates that nature-of-science aspects may be elaborated in primary school courses, as even very young pupils carry nature-of-science naïve ideas and discuss and develop them in the context of nature-of-science informed courses, e.g. work on the distinction between observation and inference, the role of experiments and creativity on scientists' work (Lederman and Lederman 2004; Akerson and Donnelly 2009). Researchers still work on how explicit-reflective instruction could improve young students' understanding of the nature of science. Students participating in nature-of-science explicitly based courses seem to improve their understanding of nature of science aspects however the levels of improvement vary across different aspects e.g. the tentative nature of science, the roles of observation in scientific work (Quigley et al. 2010).

In our case, an explicit mode of instruction has been followed with students attending the last year of primary school. Data coming from our analysis may highlight the influence of nature-of-science informed courses on pupils' ideas concerning the role of observation, the development and the dynamics of a hypothesis (e.g. promising hypothesis lead to better interpretations of data), the interaction of science and mathematics, the introduction and modification of scientific models as well as science and society interrelations (e.g. the role of a scientists' cultural background on the formation of theories).

3.4 Step 4: Comparing Data From the History of Science and Science Education

A comparative analysis of data coming from *Steps 1* and *3* indicates interesting similarities between learners' explanatory models reported till now and scientists' models in the history of science concerning the Earth, the sun, the planets, their movements and positions in the universe. For example learners' explanatory models a, b, and c presented in *Step 3* refer to a geocentric universe reminding us the theories of scientists in the past who supported this worldview. While, learners' explanatory models d, e, f presented in *Step 3* refer to a heliocentric universe similar to scientific theories about the moving Earth (around the sun). Learners' alternative models exhibit different levels of explanatory power (Thagard 1992; Liu 2005) and may guide science educators to develop teaching sequences with a gradual

[5] On this point (see Hodson 1998; McComas 1996; Driver et al. 1996; Jenkins 1996; Clough 1997; Matthews 1998; McComas et al. 1998; Akerson et al. 2000; Schwartz et al. 2004; Abd-El-Khalick and Akerson 2004; Lederman 2007).

[6] On this point (see Lederman 1992; Ryan and Aikenhead 1992; Shapiro 1996; Driver et al. 1996; Leach et al. 2000; Lederman et al. 1998; Johnston and Southerland 2001).

introduction of the various models of the Earth and sun, from the least to the most complicated ones.

As the development of individual children's thinking on the solar system in many aspects keeps pace with the historical development of scientific ideas, history of science may offer a fruitful perspective for instructional design and learning opportunities for a variety of subjects to be discussed in the classroom such as:

- scientific concepts (e.g. planet, star, model)
- scientific processes (e.g. observation, hypothesis) and
- other aspect of the nature of science, e.g. "scientific ideas are affected by their social and historical milieu", "science is dynamic, changing and tentative" (McComas et al. 1998, Bell et al. 2000).

3.5 Step 5: The Geocentric-Heliocentric Debate in the History of Science

In *Step 5* of the research, we focused mostly on the transition phases between the various theories about the geocentric and heliocentric models of the cosmos described in *Step 1*. We tried to select key-stories highlighting the evolutionary character of scientific knowledge as well as the cultural interrelations of science and society. For example periods of debate we mostly studied were: (a) Aristotle's versus Aristarchus' model, (b) Aristotle's–Ptolemy's cosmology versus Copernicus' heliocentric system, (c) Copernicus' axioms versus Brahe's model, (d) Aristotle's versus Galileo's worldview.

The history of the shift from the Earth-centered cosmos to the sun-centered model carries important aspects of the nature of science, the philosophical and cultural dimensions of scientific theories. From the standpoint of science, the passage of human thought from the geocentric to the heliocentric system clearly reflects the human effort to understand the world and when told as a story to the pupils, most of them find it very interesting. Nevertheless, the birth of modern science is closely connected with astronomy. Astronomers in antiquity showed remarkable skill in developing theories and applying mathematical devices to interpret the motion of the stars and planets as presented in Step 1. The story of how philosophers and scientists in the past came to create and then abandon the Ptolemaic system is among the most interesting and dramatic narratives in all of history (Crowe 2001). The ideas of Aristotle's and Ptolemy's models of the universe, were widely accepted and became very influential till the Middle Ages. However, astronomers were becoming increasingly aware that Ptolemy's model did not lead to completely accurate predictions. In Comentariolis (1514, in Repcheck 2007), a manuscript written by Copernicus presenting his theory developed between 1503–1513, is stated that:

> Having become aware of these defects, I often consider whether could perhaps be found a more reasonable arrangement of circles, from which every apparent in equality would be derived and in which everything would move uniformly about its proper centre as the rule of absolute motion requires. (Copernicus 1514, in Repcheck 2007, p. 54).

The Copernican revolution was a revolution in ideas, a transformation in man's conception of the universe and of his own relation to it (Kuhn 1985). According to A. Koyre:

> The development of the new cosmology, which replaced the geo or even anthropocentric world of Greek and mediaeval astronomy by the heliocentric, and later, by the centerless universe of modern astronomy, played a paramount role in this process …a deep revolution which changed the very framework and patterns of our thinking. (Koyré 2008, p. 6)

For Copernicus all the pieces fitting at last together, when he suggested his heliocentric theory. Again in Comentariolis (1514) one can read the following comments of Copernicus:

> Not only do all the phenomena follow from that but also this correlation bind together so closely the order and magnitudes of all the planets and of their spheres or orbital circles and the heavens themselves that nothing can be shifted around in any part of them without disrupting the remaining parts and the universe as a whole. (Copernicus 1514, in Repcheck 2007, p. 56).

Scientists in the past, trying to understand and describe the universe and the "position" of earth in it, have developed a variety of ideas, models and theories that carry also nature-of-science aspects such as: (a) When is a model reliable enough? (b) What evidence supports or denounces a theory? (c) How observation may lead to the formation of new ideas or reshape old-ones?

3.6 Step 6: Designing Instructional Material and Activities for the Classroom: The Case of the Geocentric-Heliocentric Debate

Based on the research in scientist' work that promoted the change of scientific ideas carried out in *Step 5*, we designed instructional material and activities for the 6th grade of the greek primary school. The instructional material included selected authentic or translated texts and designs from historical sources concerning models and theories, short stories written by teachers presented the work and worldview of scientists in the past, films about the life and work of philosophers and scientists who worked on the heliocentric-geocentric debate (films were necessary in some cases for pupils to appreciate the significance of models such as those explaining retrograde motion). The above material was supported by worksheets developed with a main focus on pointing out the succession and evolution of models as well as the nature-of-science aspects involved. Both the designed instructional material and the activities supported a teaching scenario developed in the context of collaborative inquiry which stems from socio-cultural orientations (Wells and Claxton 2002). The developed teaching scenario is focused on the participation of pupils in gradually evolving discourses and practices concerning geocentric-heliocentric debate encouraging an appreciation of aspects of the nature of science.

Through their involvement with the activities of the teaching scenario pupils are expected to study milestones, interesting events concerning the geocentric-heliocentric debate and the assumptions on which the proposed cosmological models were based, to reflect on the evolution of scientific ideas through the study of key-stories and to discuss about important aspects of the nature of science, such as:

- How has science knowledge developed? What is the value of observation, hypothesis and scientific model in doing science?
- What procedures and practices are followed by the scientists? For example, pupils have the opportunity to « follow » the shift from naked-eye observation towards observation using instruments, not to mention the shift from simple observation to the interpretation of observation data.
- How do social and cultural contexts affect the way scientists work? For example, in our case, Aristarchus' heliocentric system was not welcomed and accepted, as an acknowledgment of the motion of the Earth around the sun seemed contrary both to the religious beliefs of that time, as well as to the prevailing -based on experience-intuitive idea of Earth's immobility.

At the same time, the developed activities aim to gradually make pupils familiar to the "language" of animation and in particular:

- To improve their communication skills and be introduced to the use of audiovisual and digital technology.
- To act as critical "readers" and designers of audiovisual material.
- To be able to understand the intrinsic elements of the audiovisual language, such as the rhythm of the successive pictures to produces a stream of unbroken motion, montage, synchronisation, music, sound, etc. and can creatively use them for their learning needs.

A variety of narratives support the developed teaching activities of our educational scenario such as movies, animations, discussions. Pupils are asked to work on developed worksheets and to produce their own narratives: animation movies concerning the geocentric–heliocentric debate inspired by the history of science.

In this *Step 6* it is important to note that not only the researchers and the teachers designed instructional material inspired by the history of astronomy but in the developed activities students are also asked to develop audiovisual material–their narratives–also based on the history of science. This hasn't been an easy task. It needed to compile knowledge and expertise coming from different fields: (a) science education, (b) animation and film-making, (c) history and philosophy of science. The researchers and authors of this paper serve the above fields and their interactions (history and philosophy of science in science education, animations for science education).

The activities of the educational scenario designed for the application of our case study are described in phases below:

1st phase: Introduction (duration: 2 h)

1. Pupils discuss their views about the succession of the cosmological models.
2. Pupils watch a movie relative with the history of the cosmological models aiming to provoke pupils' interest.
3. Pupils watch exemplary animation movies that have been created form other pupils in the context of other projects in order to get familiar to the technique of animation.

2nd phase: Pupils research in the history of science (duration: 4 h)

In this phase, pupils work on worksheets and instructional material (previously developed based on the history of astronomy until the ages of Copernicus, Galileo and Kepler). Following the "time line" technique pupils are asked to complete a semi-filled table (the activity is a modified one that is proposed in the site "Science in Society–The Nuffield Foundation: http://www.scienceinsocietyadvanced.org/as/, Hunt 2008). They are asked to write (a) a scientific event, (b) the scientist that was involved with the study or development of that event, (c) the scientific processes that corresponded (according to the pupils) to each scientist and each, as presented in the example at Appendix 1.

The activity is developed in order to provide to pupils a historically informed environment to experience a way to "research" in the history of science and discuss on questions like the following:

- Are always our perceptions, such as vision, a reliable way to study the physical world?
- What reasons led in the defeat of the Aristarchus' views concerning a sun-centered model?
- How has the way of observing things changed during the centuries?
- How did the use of telescope by Galileo affect the geocentric-heliocentric debate?

Each group works on the instructional material using the designed worksheets but all groups interact in discussions and activities (for example when they watching a film). Pupils study the work of each one of the philosophers and scientists presented in the worksheet presented at Appendix 1, they work in groups, present the results of their work to the whole classroom and discuss with the guidance of their teacher. The teacher encourages and supports discussion in order to attract the attention of pupils and facilitate the communication of their ideas concerning the scientific events and processes implied by the work of scientists (see Appendix 1) and highlight the nature-of-science aspects mentioned above.

3rd phase: Pupils select a narrative technique (duration: 2 h)

Pupils are asked to choose a narrative technique in order to organize and synthesize the material they studied. Different narrative techniques are presented to the pupils as well as their advantages and disadvantages in order to help them choose the one most suitable to the scenario they are going to develop. Among the narrative styles presented are dialogue, narration (with the narrator being present or absent), written text on display and flash back techniques. Pupils in groups of three write their own scenarios to be used for their animations. Each group decide on the topic they want to develop in their story, some present the worldview of a certain scientist while others focus on an issue of disagreement or debate and present a set of contradicting views. All the information they needed in order to elaborate their scenario came from the developed instructional material based on selected texts, designs and films.

4th phase: Pupils produce materials for their movies (duration: 4 h)

Pupils decide on the way they present their thoughts and comments concerning the geocentric - heliocentric debate in an animation movie and prepare the texts. Each group of pupils is encouraged to write the synopsis of their movie, to create a story board and a flip book.

5th phase: Pupils discuss on the proposed movies (duration: 2 h)

Every group explains the way of their work during writing the synopsis of each movie, creating story boards and developing flip books. They suggest, compare styles of work and decide on new approaches.

6th phase: Pupils film their movies (duration: 4 h)

Pupils in this phase:

- Create the scenes of the movies and their elements using a variety of material (e.g. plasticine, cloths, papers, drawings).
- Dramatize and record the texts of their movies using digital media.
- Film their final animations and create short movies.

7th phase: Pupils present their movies (duration: 2 h)

In this last phase, every team presents its movie. During this procedure, pupils comment on the movies and on the scientific theories, models, concepts and ideas presented in the developed animations. Pupils are also encouraged to discuss aspects of the nature of science involved in their adapted scenarios.

3.7 Step 7: Evaluation of the Developed Instructional Material and Activities

In *Step 7* we carried out an application and evaluation research on the developed activities and instructional material. The research took place in a public primary school in Athens (Greece) during the spring of 2009. The course was attended by 18 pupils that were 12 years-old (at the 6th grade of the greek primary school). The initial phase design consisted of 20 teaching sessions (the duration of each session is 45 min) as presented in *Step 6*. However, the whole intervention actually lasted 30 teaching sessions as the pupils themselves after creating the first 6 short movies they asked to go on and repeat a second circle of animation production that led to 8 more short films and a final film that is a synthesis of the previously developed 14 short movies. These 30 teaching sessions took place in the context of the science sessions (three teaching sessions per week) and during the flexible zone (2 teaching sessions per week). The flexible zone is a special part of the greek curriculum where the teacher has the opportunity to try new teaching approaches. Therefore, the implementation actually lasted 6 weeks.

During the application pupils used the developed worksheet (inspired by the history of science), studied historical texts (elaborated to fit their age group), watched movies and animations concerning the teaching content (e.g. the retrograde motion of planets) and discussed about the content (concepts, models etc.), the philosophers and the scientists who supported the various theories, the social and cultural context around each theory and other aspects of the nature of science. Pupils in groups developed scenarios, made story-boards and flip-books, performed their stories and/or constructed materials and photographed them, filmed dramatized actions or developed moving stories from still pictures, recorded sounds and proceeded to the final cut of their short films (Fig. 3).

Pupils in this case developed 14 short films and one synthesis film (a total of 15 films). Some of the titles of the films are: “Aristarchus”, “Ptolemy”, “The Synthetic Model of Tycho Brahe”, “Retrograde Motion”, “Disagreement in Science”, “Galileo”, “Kepler”, and “Copernicus”. In the 5th phase of the teaching scenario presented above, during the classroom discussion about the films under development, pupils decided also to integrate most of their movies in one film (actually a synthesis of a variety of the developed short movies) on the geocentric–heliocentric debate. This basic scenario is presented in Fig. 4.

Pupils created their films using drawing, pictures, real-life objects or recreated representations of real objects, their own bodies (photographed or filmed) and 3D hand made models (Fig. 5).

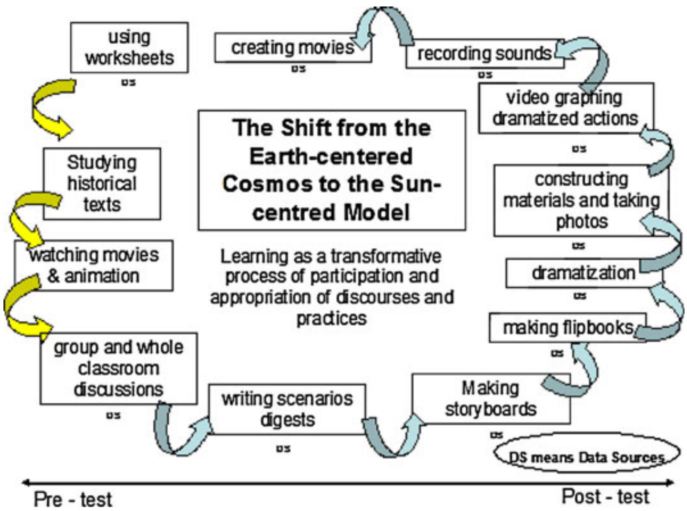

Fig. 3 Pupils activities and data inputs for evaluation during the application

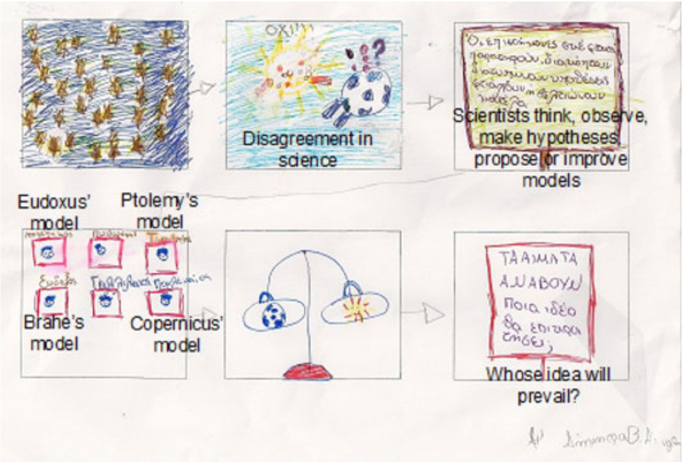

Fig. 4 The story board of the pupils' film that integrates a variety of developed short movies

Fig. 5 A 3D hand made representation of Tycho Brahe's model developed by pupils

In this phase many data have been collected and analysed. GNOSIS is the main research model employed for the development of research tools (questionnaire) and the analysis of data. The GNOSIS research model (Fig. 6) was initially developed in 2007 (Seroglou and Aduriz-Bravo 2007) and since then it has been used for the analysis of more than 10 case studies by the ATLAS research group (Tsarsiotou et al. 2009; Vogiatzi et al. 2009). GNOSIS is an acronym for 'Guidelines for Nature Of Science Introduction in Scientific literacy' and has been developed based on previous theoretical frameworks developed (Seroglou and Koumaras 2001; Aduriz-Bravo 2003; Seroglou 2006). GNOSIS approaches NOS-informed science teaching through three complementary dimensions (Seroglou and Aduriz-Bravo 2007):

1. The *cognitive dimension*, dealing both with science as a set of models that give meaning to the world (*nature of science contents–G1*) and with the broader social contexts in which such ideas have come to be (*nature of science contexts–G2*).
2. The *meta-cognitive dimension*, focussing on what science is (*synthetic nature of science as a product–G3*), how science changes in history (*nature of the evolution and*

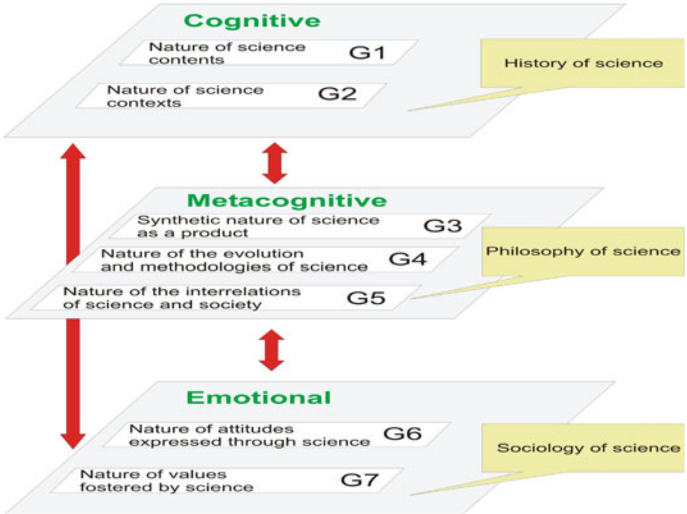

Fig. 6 The GNOSIS research model

methodologies of science–G4), and how science relates to society and culture (*nature of the interrelations of science and society–G5*, in which the 'cultural print of science' can be appreciated).

3. The *emotional dimension*, which opens the picture to considering attitudes (*nature of attitudes expressed through science–G6*) and values (*nature of values fostered by science–G7*) that are not only fundamental in science as a process, but also desirable in the education of scientifically literate citizens.

Data analysed in this phase came from the following sources:

(1) Worksheets filled by the pupils (an example is presented at Appendix 1).
(2) Videotaped and recorded discussions in the classroom during most of the phases of the teaching scenario and interviews with the pupils and the teacher after the implementation (data coming from the analysis of an interview with pupils are presented in Appendix 2 and commented below).
(3) Questionnaires distributed before and after the implementation focusing on nature of science understanding and on interest and motivation concerning science learning. A Likert-scaled questionnaire was developed with items corresponding to the GNOSIS model categories (selected data are presented below).

For a full version visit: http://www.hipstwiki.wetpaint.com/page/questionnaire.

(4) Flip-books, story-boards and audio-recording of the pupils, not to mention the developed short films and the final synthesis film have been analysed using the GNOSIS research model. These visual and audio-visual data have also gone through semiotic analysis focusing on verbal and written text, material objects and body language.

In this paper we present some examples of data analysed by the GNOSIS research model. The presented data come from the questionnaire, group work on a worksheet, a flip-book idea, story-board development, one of the short films produced and an interview with pupils. The rich research data and the multiple data analysis has provided us with results that are to be presented also in future papers and research reports.

3.7.1 Questionnaire Data Analysis: Some Examples

A Likert-scaled questionnaire has been developed with items corresponding to the categories of the GNOSIS model. The questionnaire was distributed before and after the implementation (http://www.hipstwiki.wetpaint.com/page/questionnaire).

The questionnaire was answered by 15 pupils before and after the course (3 out of the 18 pupils were absent when the questionnaire was distributed). Questionnaire analysis verifies a positive influence on pupils ideas concerning the nature-of-science aspects elaborated in our case. Five examples are presented:

(1) In item 6 of the questionnaire pupils' answers point out their ideas concerning the statement: "Truth does not change in science". This statement corresponds to G3 of the GNOSIS model concerning the relation between the "quality" of truth and scientific products (theories, models etc.). Pupils' answers before and after the implementation are presented in Fig. 7. As the diagram shows students before attending the nature-of-science course either were not sure or they supported the ideas that indeed "Truth does not change in science". However, after the course most of the pupils (9 out of 15) shift towards the view that truth changes in science revealing an appreciation of the dynamic character of scientific theories and models.

(2) In item 9 of the questionnaire pupils deal with the statement: "Scientific explanations may change in time". This statement corresponds to G4 of the GNOSIS model concerning the evolutionary character of scientific explanations. Pupils' answers before and after the implementation are presented in Fig. 8. Pupils before attending

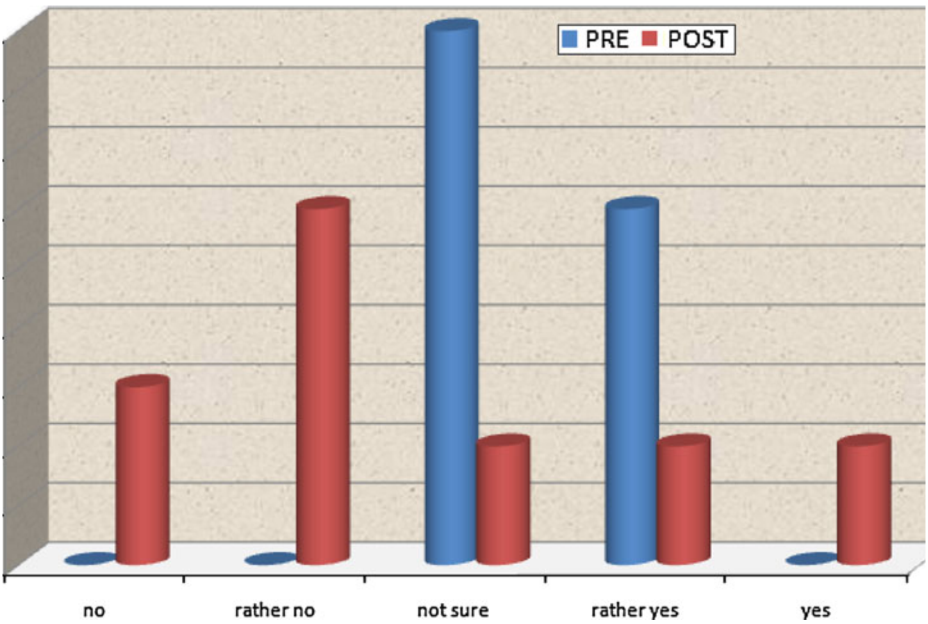

Fig. 7 Pupils' answers to questionnaire item 6–"Truth does not change in science"

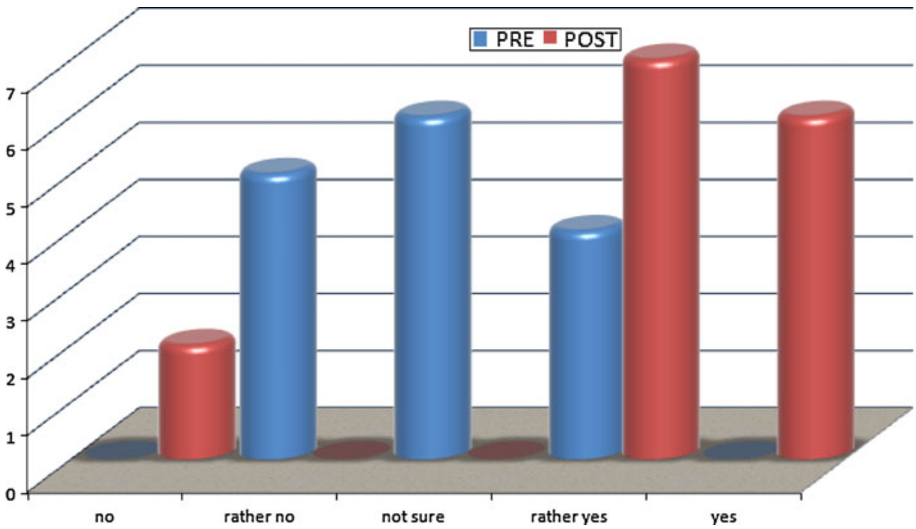

Fig. 8 Pupils' answers to questionnaire item 9–"Scientific explanations may change in time"

the nature-of-science course were not sure about their ideas on the subject. After the course most of the students (13 out of 15) shift towards the idea that scientific explanations may change in time.

(3) In item 10 of the questionnaire pupils face the statement: "Scientific explanations may be completely replaced by new explanations if new evidence supports that". This statement corresponds to G4 of the GNOSIS model concerning the evolutionary character of scientific explanations and the interaction of evidence and theory formation. The shift of pupils towards the acceptance of the above statement (12 out of 15) is surprisingly encouraging as shown in Fig. 9.

(4) Item 11 of the questionnaire presents the statement: "All scientists follow the same scientific method". This statement corresponds to G4 of the GNOSIS model concerning the idea of the existence of only one scientific method, an idea reflected by traditional science teaching and curricula for years during the second half of the twentieth century. In our case pupils deal with a variety of scientific methods and this seem to grow on them as at the end of the implementation 13 out of 15 pupils support that there isn't only one scientific method (Fig. 10).

(5) In item 12 of the questionnaire pupils face the statement: "Scientists do research in different ways". This statement corresponds to G4 of the GNOSIS model concerning variety and evolution of scientific methods of research. Once more a shift of pupils' ideas is recorded towards the acceptance of the above statement (12 out of 15) as shown in Fig. 11.

3.7.2 Worksheet Data Analysis: An Example of Group Work

In Appendix 1, we present a translated in English worksheet used in the 2nd phase of step 6 of SHINE. In this phase pupils with the guidance of their teacher were asked to point out the scientific "event" taking place and the scientific process (or processed) used by scientists in the past based on information given to them from the history of science. The third

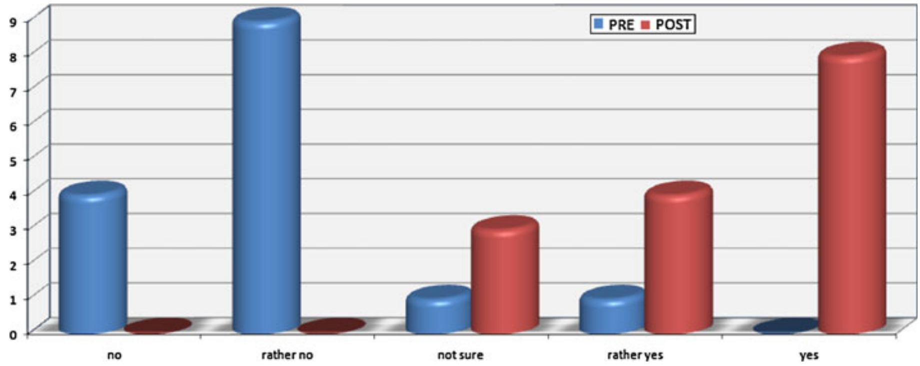

Fig. 9 Pupils' answers to questionnaire item 10–"Scientific explanations may be completely replaced by new explanations if new evidence supports that"

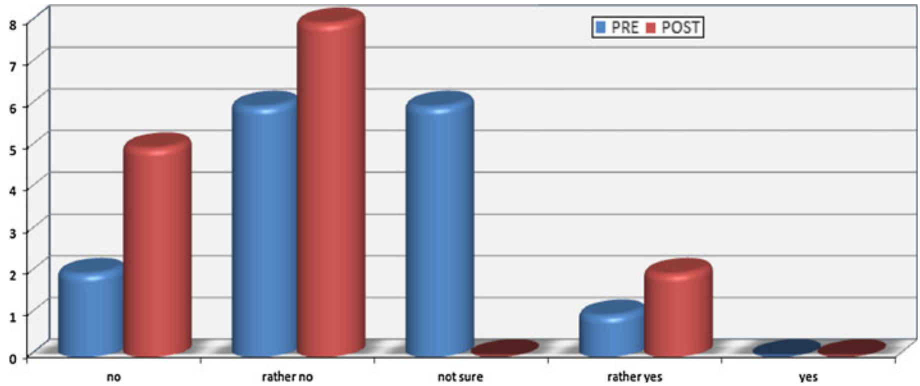

Fig. 10 Pupils' answers to questionnaire item 11–"All scientists follow the same scientific method"

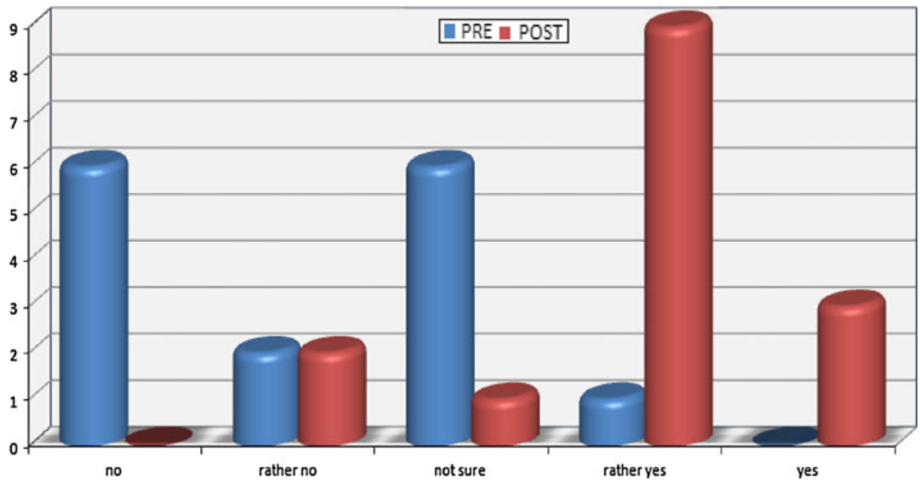

Fig. 11 Pupils' answers to questionnaire item 12–"Scientists do research in different ways"

and the fourth column of the worksheet in Appendix 1 titled “Scientific event” and “Scientific process” were filled by a group of three pupils. In the twelve selected episodes coming from the history of science pupils comment both the content of science using both scientific and mathematic vocabulary as well as a variety of aspects of nature of science concerning scientific processes.

About the content of science, pupils use scientific and mathematic terms such as geocentric model, heliocentric model, system, planet, star, retrograde motion, movement (of planets), telescope, centre (of orbit), sphere, epicycle, measurement, elliptical movement, evidence. These terms, although pupils are just introduced to the scientific discourse, are used in a correct way (in most of the cases) and are coherent to the understanding of the pupils of the ideas and the explanatory value these terms reflect as the recording of the conversations of the pupils verify. Also, as this phase is to followed by the developed of story-boards, flip-books and films pupils have again and again the opportunity to mature in scientific discourse and get more and more acquainted to the new scientific and mathematic terms.

In the comments of the students written down in the worksheet many nature of science ideas appear. An attempt to analyse pupils’ comments using the GNOSIS model is presented in Fig. 12.

In the worksheet, pupils comment on 12 episodes from the history of science. As one may observe in all the episodes pupils discuss about the nature of the content of science (G1) as well as about the content itself. This is an example of a teaching procedure focused on nature of science understanding where the content of science is also elaborated in the classroom. Of course, we should mention the teachers’ guidance and encouragement in order to maintain the focus of classroom discussion. The other two main GNOSIS categories that have been mostly recorded in the data coming from the worksheet are G3-synthetic nature of science as a product and G4-nature of the evolution and methodologies of science. Pupils comment the creation of models (G3) and the effect of data and observation on the development and change of models (G4). In the tenth episode (the case of Tycho Brache) pupils chose to stress the idea of science-society interaction (G5) and imply the nature of attitudes (G6) and values (G7) fostered by science. We should also, point out that in the third episode that refers to Plato pupils comment on the idea that mathematics and geometry should be used in science presented this mathematical context of science understanding (G2-nature of the context of science) and in the 12th episode about Galileo pupils suggest that the effect of technological gadgets (e.g. telescope) to the data collection for offering support of counterevidence for theories.

In this case, pupils discuss about the nature of science and use a nature of science vocabulary that is explicitly guided by the teacher and the instructional material that is based on history of science. In their discourse, pupils use a hybrid language carrying nature of science ideas in school science language. We consider this a first step, an introduction to scientific repertoire that may grow on pupils as the go on working on scripts, story-boards, flip-books and movies development.

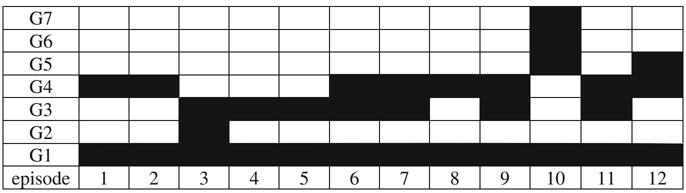

Fig. 12 An example of worksheet data analysis

3.7.3 Flip Book Analysis: Galileo and Football

Pupils in the fourth phase of step 6 of SHINE work in groups and create flip-books about the geocentric—heliocentric debate. Pupils are free to use and embody in their stories their hobbies, interests and everyday habits. In the example we are presenting here, three boys discuss about Galileo's ideas using the background of football terminology. They use their hobby and interest in football to discuss about science. They use the image of the terrain of a football stadium in order to present Galileo's ideas and how this contributed to shift from the model of Ptolemy to the model of Copernicus (see Fig. 13).

Pupils created a succession of 14 images for their flip-book (six of them are presented in Fig. 13). Pupils made 2 drawings and then photographed them 14 times for creating the flip book. The flip book begins with the image of a terrain that represents the geocentric model. Then the drawing starts to gradually turn up side down and the heliocentric model is revealed on the other side of the initial drawing. This way the change of models is presented as the turning of a page. Pupils enjoyed a lot the creation of this flip-book and were happily surprised that they could use their interest in football and do science.

When analysing this flip-book in the context of GNOSIS, we observe that in this case pupils present the content of science (G1) in a context that is inspired by football (G2). They present the change of models and the evolution of science (G4) and they have inputs of science-society interactions (G5) both of today (e.g. football) and of the past (e.g. Galileo and the church). Nevertheless, they present attitudes (G6) and values (G7) that come from scientific as well as from football debates.

3.7.4 Story Board Analysis: The Final Film

Pupils created 14 story boards and short films in groups. However, they decided to use material coming from all these films in order to create a final film (the 15th production of the film series). The story board of the final film is presented in Fig. 4.

In their narrative, the observation of the sky and of the movements of the stars has created many theories to interpret the movements of the planets and to support ideas about

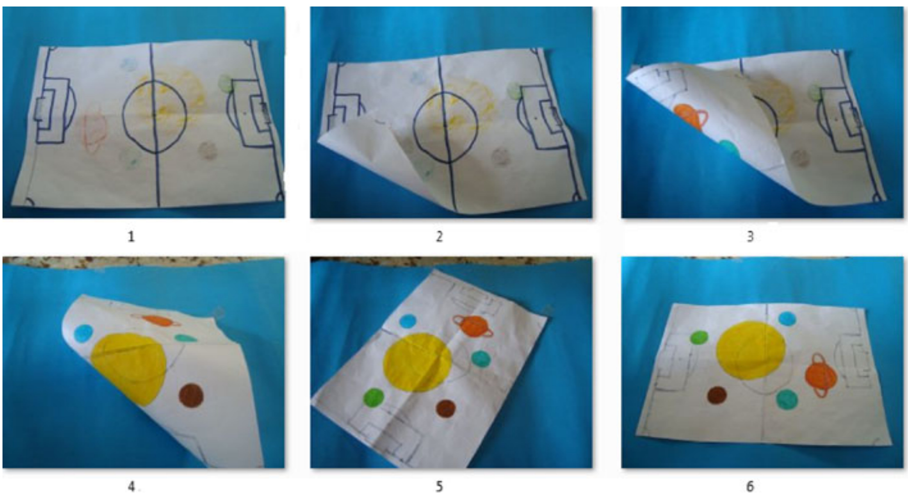

Fig. 13 Selected images from the "Galileo and football" flip-book

the position of the earth in the universe. An imaginary conference is taking place where all scientists and philosophers from the past that have taken part in the heliocentric-geocentric debate are presenting their ideas to the public. The short film is produced in order to be presented in the media and advertise the conference. In the story board pupils decide to start from the observation of the sky, then present the disagreement in science that the observation of the stars has provoked, also support that scientists think, observe, make hypothesis, propose or improve models. The story board goes on with the parallel presentation of the models of Eudoxus, Ptolemy, Brahe, Copernicus etc. The models are compared and debated and the story board closes with the question "which idea will prevail?", or which model or theory will be proved to be the strongest one.

In the GNOSIS context, in their story board pupils discuss the nature of the content of science (G1) in the context of the historical episodes and the imaginary conference (G2), present the creation and evolution of models (G3, G4), the debate of models and scientists and their cultural inputs (G5) accompanied by the attitudes and values in stake (G6 and G7).

3.7.5 Film Data Analysis: "The Synthetic Model of Tycho Brahe"

The short film analyzed here is titled "The Synthetic Model of Tycho Brahe" and is one of the 14 short films produced by pupils. The duration of the film is 43 s and has been developed by three 12-year-olds who created 3D-representations of Brahe's model (Fig. 5), photographed 3D real objects and performed themselves. In the film, Tycho Brahe presents his model to the public. His model is an attempt to synthesize the models of Copernicus and Ptolemy. According to his model all the planets move around the sun and this "system" as a whole moves around the Earth that is located in the centre of the universe. In the film developed by these three pupils, the public rejects the model that is proposed by Tycho Brahe and shows this disapproval by throwing tomatoes and other vegetables to Brahe. The short film goes on representing once more the model of Brahe, this time with moving pictures composed by photographs taken by the three pupils. In this succession of still pictures the thrown vegetables move in space and gradually form the planets around the sun and represent the movement of this system around the Earth (Fig. 14).

The study of the videotaped and recorded interactions of the three pupils during the creation of the film shows that they initially intended to present the nature of science and society interrelations (G5): The scientist attempts to convince his contemporaries but they disagree and make fun of him. At the same time the scientist tries to compromise two worldviews (G3), the new "alternative" supporting that the planets move around the sun and the old "traditional" worldview supporting that all celestial objects move around the earth. His hybrid model as presented in this short film resembles a lot the hybrid explanatory models of pupils recorded in science education researches (products of the synthesis of pupils' ideas and the textbook science reproduction).

Also the film reveals the in-depth elaboration in the classroom of how scientific models are created (G3), how these models support scientific explanations and change in time in order to readjust with new observations (G4) and the efforts of the scientists to communicate their models to the people either laymen or specialists in their field (G5). In order to make the film, the three pupils created 3D representations of Brahe's model (and this took place even in their free time as if science "followed" them out of the classroom). Another interesting point is the last part of the film where once more Brahe's model is presented using the vegetables thrown to him by the public. Pupils this way comment on scientist's

Fig. 14 A still picture of the planets moving around the sun using the real objects "thrown to Brahe by the public" in the pupils' short film

commitment in his model and his persistence to move science forward even against the "main stream".

The GNOSIS model when used to analyse this short film reports the development of nature of science aspects elaborated. In Fig. 15 the GNOSIS analysis is presented in time periods of 8,5 s. In the first time period the film stressed on the nature of the evolution of science (G4), that new models of the universe come to change, alter or improve the previous ones. For example, in the film the pupil-journalist asks the pupil-Brache: "which model about the universe do you believe that will prevail?" In the second time period both the content itself is being presented (G1) and its nature being questioned (what is a model?). The pupil-Brache in the film supports that "I believe that all planets will move around the sun and this system of the sun and the planets as a whole will move around the earth". Also the attitudes of the scientist and the public encouraged by science are brought forward (G6). In the film Brache supports his ideas despite the anger and opposition of the people. In the third time period the nature of the interrelations of science and society (G5) coupled with comments on the nature of the social and culture context (G2) appear. In the film the public throws potatoes, tomatoes and other vegetables to Brache showing their disapproval and mocking his ideas. In the fourth and fifth time periods the content of science (G1), its nature and the nature of the evolution of science (G4) are again elaborated as the thrown vegetables animated are reorganised to present Brache's synthetic model.

G7	nature of values fostered by science					
G6	nature of attitudes encouraged by science		■			
G5	nature of science – society interrelations			■		
G4	nature of the methodology and evolution of science	■			■	■
G3	synthetic nature of science as a product					
G2	nature of the context of science			■		
G1	nature of the content of science		■		■	■
	Time period	1	2	3	4	5

Fig. 15 Pupils' short movie analyzed by GNOSIS (each time period has a duration of 8,5 s)

If we follow the succession of steps concerning the teaching and learning of nature of science introduced by pupils in this film, we observe that they present their ideas in an interesting and communicative way. In our attempt to analyse the material produced by pupils, more and more we realize that this rich pool of data could help teachers, researchers and educators redesign their projects concerning history and philosophy of science in the classroom and nature of science understanding. We look forward in analysing more of our material also using semiotic analysis of text, material objects and body language and having more results (also coming from follow up implementations) to present in future papers, nevertheless these first results show that we are in the beginning of a promising research field.

3.7.6 Interview Data Analysis: Aftermaths of a Nature-of-Science Implementation

A week after the end of our nature-of-science course, interviews of pupils in groups took place. The interviews were also analysed using the GNOSIS model. The GNOSIS analysis of the interview with two pupils is presented in Appendix 2. The interview had a semi-structured character. The researcher had prepared nine questions to discuss with the pupils focusing on whether they enjoyed this nature-of-science informed teaching approach and their ideas about content and nature of science aspects. However, the researcher let the discussion move towards other paths as well following the needs of pupils to express their ideas and proposals concerning science teaching.

Watching the interview flow in the GNOSIS matrixes in Appendix 2, we observe that the discussion starts and finishes with comments on the nature of attitudes encouraged by science (G6) while this topic is a lot elaborated during the discussion as well. Their comments concern: (a) their attitude towards this nature-of-science informed teaching approach and (b) the resistance of society to new ideas coming from the field of science. For example, one of the pupils, Giorgos, says: “I liked it (the course) a lot! It was fun. I laughed and I had a good time. I liked the fact that we had different ideas on how to make the final film. I have nothing negative to say, I like it all”. These are not usual comments for a science course. The animation introduction coupled with the history of science that provided the background for the animations made the difference. Both of the pupils present interesting comments concerning the resistance to theory change coming either from the public or the scientists. For example Giorgos supports that: “New ideas were refuted because people was used to old ideas. And this was not easy to change”. The other boy, Miltos, adds: “People change gradually. After big decisions they take. The need discussions, evidence, arguments, examples”.

A big part of the interview is focused on the formation of models and scientific knowledge (G3). For example Miltos suggests that: “We learned about the evolution of science, how things we now learn were formed in the past. (Science) wasn’t as we now know it from the beginning; it was shaped in the course of time”. And Giorgos adds: “Because in many case we learn that something is right and we believe that it will remain forever, but it isn’t so.” We observe that there is a coherence of pupils’ responses in the interviews with the data analysed in the previous examples coming from the film, the storyboards, the flip-book, etc.

Pupils also discuss about the nature of the methodology and the evolution of science (G4). Giorgos argues that: “Scientists observe, study, and then start to shape their model about the planets and their movement using various tools like the telescope for example”. They also comment the science-society interrelations. In a part of the interview Giorgos supports that: “Religion may affect (science). Like in the past, when people considered earth to be sacred and in the centre of the world". Miltos goes on saying: "The Christian religion was in favour with Aristotle who believed that the earth is in the centre of cosmos".

Finally, even in the interview, when pupils discuss about the course they comment many times about the nature of the content of science (G1) and they refer to models, theories, the planets etc. This once more comes to verify that the content of science may be well taught and elaborated in a nature-of-science teaching environment.

From the analysis of the interview, we observe that after the end of the course, pupils discuss about nature of science issues fluently and without even being asked to. It seems that they have shifted from just talking science to be able to talk about science, about the many aspects of the nature of science. To this direction helped the fact that they were gradually introduced to nature-of-science activities informed by the history of science. These activities were at the beginning of course guided by the teacher, but as the course moved on the activities became more and more student-centred and pupils took initiative in the context of involving history of science and nature of science issues in their films. This fading guidance coupled with genuine encouragement of the pupils to create "instructional" material, films that helped them to learn and discuss about science.

3.8 Step 8: The Contribution of the History of Science in Science Learning

In Step 8, a comparative study of the results coming from the application of the developed instructional material and activities (SHINE–step 7) and from the research in the history of science concerning the geocentric-heliocentric debate (SHINE–step 5) takes place. We observe that in the current case the use of history of science in the development of teaching material and activities has contributed to pupils' attitudes, language and nature of science understanding.

3.8.1 Change Recorded in Pupils' Attitudes

Pupils participating in the implementation of the teaching scenario had no previous experience either in collaborative inquiry learning or in alternative teaching interventions (different from the "traditional" ones that are based mostly on science textbooks and official curricula). Not to mention that the use of history of science in science teaching has been totally new to them. Initially, as it is stated in the teacher's recorded classroom data, pupils made questions such as: "Are we obliged to learn these by heart?", or "Should we write tests on this material?" (The questions refer to the historical material). The students had an 'image' of what a science lesson should be: This could be briefly described as the most important things being memorized, while writing tests and working in a narrow context concerning only activities focused on the teaching content.

During the implementation of the teaching scenario there have been significant changes in pupils' attitudes. The questionnaire used in the pre- post- evaluation research in its second part included items concerning classroom interaction and self-concept about science learning. Research results indicate that pupils sifted from the idea that science courses are demanding and time consuming to the idea that not much work has been asked to be carried out during their science course. For example, many times pupils asked eagerly to work on the developed teaching scenario instead of doing science lessons in the context of the applied curriculum. For them science learning in this historical and philosophical context was interesting, fruitful, attractive and not tiring. Pupils' attitudes towards science lessons became more and more positive. Their self-concept about science learning improved and the majority of them came to believe that ‘they do very well in science courses’ and that ‘science is one of their favorite courses’. They asked for more material and information coming from the history of science and showed genuine interest in their engagement with the. Nevertheless, they also support after the implementation that science is not difficult to understand or comprehend, although many of them found ‘difficult to understand anything related to science’ before the geocentric-heliocentric debate course.

3.8.2 Changes Recorded in Pupils' Language

In the beginning of the implementation, students used everyday terminology when discussing about the geocentric-heliocentric debate. During the application of the teaching scenario, pupils got involved actively in the use of school science language concerning this topic and also got familiar to the language of animation.

Concerning school science language they gradually started to be more specific and clear on the scientific or thinking processes during the discussions about the geocentric-heliocentric debate. For example, in the initial phase of the implementation, pupils used general phrases such as “scientists think…” for a variety of scientific processes (observation, hypothesis formation, model development etc.,) while later they used specific expressions like “scientists observe”, “scientist make hypotheses”, “scientist make or improve models…” making statements that accurately represented the scientific or thinking process taking place.

Also, many pupils initially in their texts and their oral speech gave the same meaning to different scientific terms such as “planet” and “model”. During the course pupils gradually defined meanings and terms (e.g. star, retrograde motion, trajectory, rotation) and used them more correctly in their narratives for their movies. This gradual change on the way they spoke and wrote about the science is reflected in the products developed by pupils such as their story boards, worksheets, scenarios digests, flip books, narrations in their movies and finally in the movies themselves.

It is also important to report that pupils improve their use of the audiovisual language of animation. They became independent in the creation of their flip books, they wrote their scenarios, recorded their animation prototypes and produced animated scenes.

3.8.3 Changes Recorded on Nature of Science Understanding

During their involvement with the activities developed based on the history of science pupils gradually became familiar with a variety of aspects of the nature of science and got introduced to the nature of the content and context of science, the nature of science-society interrelations, the nature of the development, evolution and methodologies of science as well as the values and attitudes fostered by science. The GNOSIS research model helped us analyze the questionnaires distributed before and after the implementation, the worksheets filled by the pupils, flip-books, story-boards interviews with the pupils and the developed films as the example resented previously.

The analysis of the questionnaires distributed before and after the implementation indicates for each of the GNOSIS categories the following:

(a) *The nature of the science content*: During the teaching of the course a shift towards a more skeptic and critical reading of science text books is taking place, as through the course a lot was discussed about the authenticity and the evolution of the recorded science knowledge in books.

(b) *The nature of the science contexts*: During the course students reconsider whether their contemporary conditions concerning economy, politics, religion, art etc. influence scientists in their work.
(c) *The synthetic nature of science as a product*: During the course they became familiar to the change of ideas and theories concerning the study of the geocentric-heliocentric system in the past and they seem to move beyond scientific dogmatism.
(d) *The nature of the evolution and methodologies of science*: Pupils seems to improve their understanding of the nature of the evolution and the methodologies of science. It is obvious that pupils were not sure initially whether scientific explanations change in time. After the course they appear to have a clear opinion on the subject and most of them agree that scientific explanations change in time. The lack in the understanding of this aspect of the nature of science has been recorded as an obstacle in the learning of science, because the different explanations of the same physical phenomenon that comes from scientists of different eras confuse and stress pupils if they don't have this overall image of science as a network of explanations that are from time to time changed and improved. Nevertheless, in this case pupils work a lot on perceiving scientists' argumentation as an intrinsic characteristic of the history of science and on getting familiar to the use of models by scientists in order to communicate their ideas.
(e) *The nature of the interrelations of science and society*: Pupils after the implementation move towards agreeing with the statement recognizing the transfer of knowledge, activities and products from science and society as well as the social effect on the contemporary use of all those in the communities of today.
(f) *The nature of attitudes expressed through science*: Concerning the attitudes expressed through science pupils after the course clearly support that science is not only for "clever" people but for all.
(g) *The nature of values fostered by science*: Pupils during the course have the chance to discuss and work on the idea that the way scientists work is influenced by what other people consider important and in their case the impact of Aristotle's theories on the geocentric-heliocentric debate had been an excellent working example.

4 Discussion

In our proposal pupil produce their own narratives that are used as modes of thinking and as structures for organising their knowledge on the issue (Bruner 2004). Data coming from classroom applications such as the one presented in this paper may offer valuable feedback for curriculum developers in science education since science curricula have been considered as "animated conversations" (Bruner 2004) on topics that cannot be fully described (this would demand a very sophisticated scientific language) and actually include animations (pictures, texts, films, demonstrations etc.) used in the process of didactical transformation of the knowledge to be taught.

A distinct characteristic of our proposal in relation with teaching strategies that were presented in the first section of the paper (e.g. the "story-line" approach, the "case study" approach, the use of computer simulations of historical experiments, the recreation of historical debates) is that pupils themselves are involved in the production of their own audiovisual narratives inspired by the history of science.

In this case, pupils, after being taught nature-of-science issues concerning the geocentric-heliocentric debate in an explicit way like others educational researchers indicate (e.g. Quigley et al. 2010), are asked to produce their own materials and to manifest their understanding on the issue. Data analysis indicates, in accordance with other researchers (Lederman and Lederman 2004; Akerson and Donnelly 2009), that nature-of-science aspects can be introduced in primary school courses with very encouraging results.

The study of the geocentric-heliocentric debate and the mission of animation movies creation by pupils give to them the opportunity to "…appreciate that new ideas often meet opposition from other individuals and groups, sometimes because of wider social, political, or religious commitments … leads immediately to the consideration of scripture and how is interpreted, authority in religion, the role of sensory evidence in determining the scientific truth …" (Matthews 2009, p. 15). Also, we believe that such approach could contribute, even in this early school age, to a first introduction in the notion of worldview as "the connections are two- way, certainly from science to worldview and metaphysics, but also from worldview and metaphysics to science" (Matthews 2009, p. 14). We saw these two connections in pupils' animations and flip books produced during the project. The Galileo's flip book example ("Galileo and football") is an occasion of how science affects, confronts and sets aside a worldview. On the contrary, Tycho Brahe's movie example ("The Synthetic Model of Tycho Brahe") indicates how his contemporary worldviews (Aristotelian–Ptolemaic and Christian worldviews) affected the scientist and his synthetic model.

The development of pupils' animation movies carrying aspects of the history of astronomy with a strong focus on the understanding of the nature of science creates a dynamic educational environment that facilitates pupils' introduction to a demanding teaching content (e.g. planet, model, retrograde motion) placing it in context (key-stories from the history of science) and at the same time offers to pupils the opportunity to engage their personal habits, interests and hobbies in the development of their science movies.

Conclusively, our cross-disciplinary proposal, shows in practice that teaching scenarios informed by the history and philosophy of science may trigger effective learning processes when accompanied with the appropriate teaching guidance and material. In our project, pupils not only became familiar with stories about the development of important ideas (Millar and Osborn 1998) concerning geocentric-heliocentric debate but themselves produce their own narratives to present them in the format of movies. Pupils, having as a main aim to create animation movies, interacted, analyzed and processed information from the history of science, chose a narrative technique, composed the material they gathered, created their own material and eventually produced their original short movies using a variety of expressive means. Pupils themselves re-contextualized science knowledge and informed the films they developed with history and philosophy of science as well as with contemporary societal and cultural aspects putting the geocentric-heliocentric debate in the wider "image of science" in the world.

Of course, a lot remain to be done in the future. There is need for improving research tools, for gathering more classroom data, for analyzing in more detail and in comparative studies the effect of history and philosophy of science informed science teaching to various populations (students, teachers etc.). The current research has revealed a part of the matrix for understanding and evaluating the effect of science teaching that is informed by the history and philosophy of science. The rest of this dynamic matrix remains to be further researched and documented in future research projects that will offer more answers, and hopefully even more research questions, to researchers in the field of history, philosophy and science teaching.

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Appendix 1

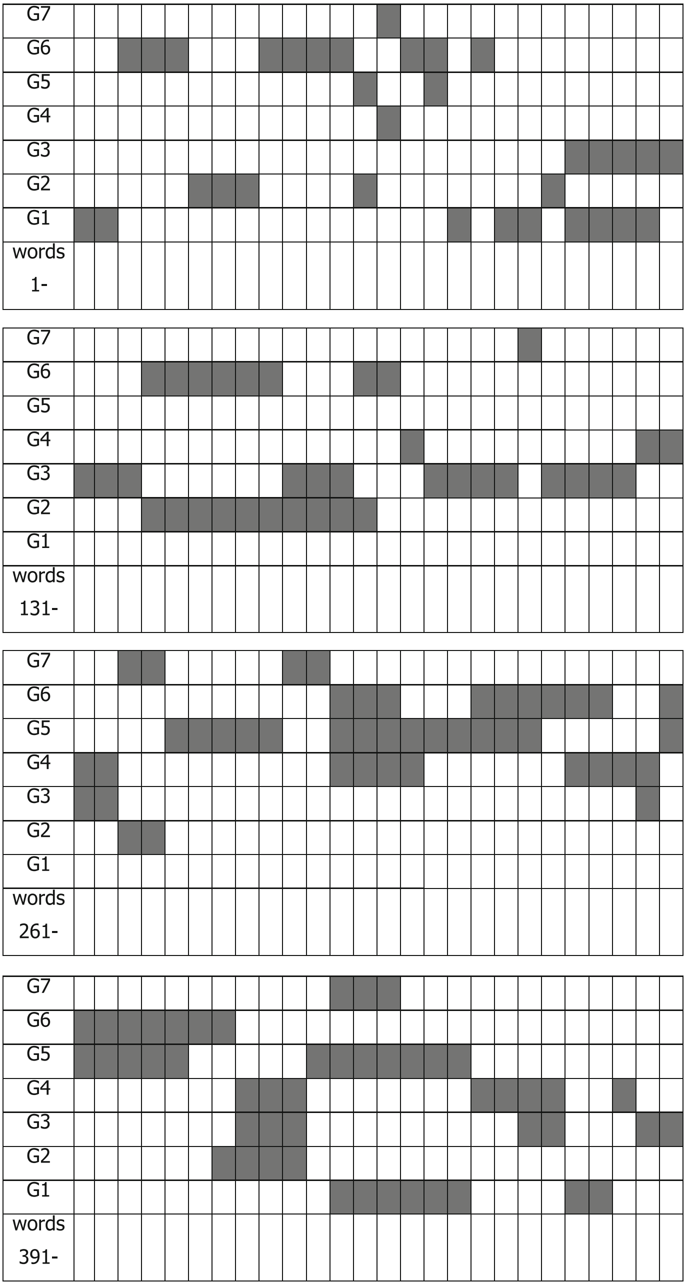
See Table 1.

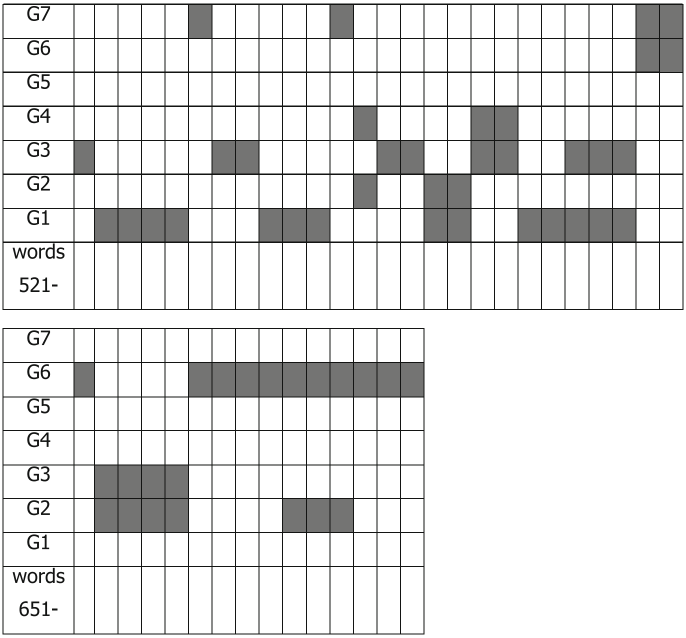
Table 1 A translated worksheet filled by a group of two students (their comments appear in italics)

Time	Scientist	Scientific event	Scientific process
ca. 700–ca. 500 B.C.	Thales, Anaxi-mandros etc.	*They observed and searched for the causes of everything they were interested in and they gave the name "planets" to the moving stars*	*Observation*
ca. 470–ca. 385 B.C.	Philolaus	*The system is neither geocentric nor heliocentric but the central fire is in the centre*	*Hypothesis*
ca. 428–ca. 348 B.C.	Plato	*Suggested that astronomers should use mathematics and geomentry*	*A proposal to use mathematics and geometry*
ca. 400–ca. 347 B.C.	Eudoxus	*Tried to solve the problem of retrograde motion of planets using 27 spheres that had a common centre*	*Proposal of a model*
384–322 B.C.	Aristotle	*Improved the model of Eudoxus and suggested 55 spheres that had a common centre*	*Uses a model and makes his own proposal*
ca. 310–ca. 230 B.C.	Aristarchus	*Proposed for the first time an heliocentric model*	*A new hypothesis leads in the creation of a new model*
ca. 240–ca. 190 B.C.	Apollonius	*For the first time the idea of epicycles is presented, that is the planets also perform a second movement beyond the movement around the Earth*	*Observation and proposal for the improvement of his model*
ca. 100 - ca.–170 A.D.	Ptolemy	*Uses the model of epicycles and improves it, defining the movement of the planets in detail*	*The existing model didn't agree to some observations and changes to the model are suggested*
1473–1543 A.D.	Copernicus	*The Sun is in the centre, the Earth moves around itself and around the Sun and the planets make circular movements around the sun*	*Observation of a new model*
1546–1601 A.D.	Tycho Brahe	*The Earth is in the centre of the cosmos but all the planets move around the sun*	*Science is influenced by social conditions and by religion*
1571–1630 A.D.	Kepler	*Uses Brahe's measurements talks for the first time about the elliptical movement of the planets*	*Modification of the new model based on observations, measurements and mathematical calculations*
1564–1642 A.D.	Galileo	*Galileo with the help of telescope shows evidence that the heliocentric model is a scientific fact*	*Evidence based on observations with the use of telescope overcome the old model and verify the new one*

Appendix 2

An interview with pupils analysed by GNOSIS.





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