Students' Difficulties in Interpreting Images and Simulations About Astronomy Phenomena

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In this paper, we investigate difficulties for students in interpreting images and simulations in astronomy. To analyze images and animations we adopted the socio-semiotic theoretical framework by Kress and Van Leeuwen. This framework allowed us to categorize images and simulations according to their representational structures -namely, the way in which symbols and signs are organized for communication. First, six images from a textbook and two internet simulations were analyzed according to the framework. Then, we designed a 40-minute interview about the phenomenon represented in the images and the animations. Analysis of answers showed that difficulties are linked to the spatial distribution of symbols and signs, the presence of real/symbolic elements, and the relationships between different images. Our results may help to inform the design of visual instructional materials.

1 Introduction and aims

Most of today's scientific (and non-scientific) communication is based on visual language. Consequently, teaching materials nowadays also increasingly exploit images and animations in order to improve students' understanding of scientific concepts. Such an increased usage of images in school leads to a tension between the interests of offering teachers straightforward, short representations, and the need for more open challenges for students such as, e.g., meaning construction and problem solving (Pozzer-Ardenghi & Roth 2005).

In this paper, we investigate difficulties students encounter when interpreting images and simulations related to topics in astronomy. The main reason for this choice is that school textbooks progressively feature photographs of Earth, as well as schematic representations of the Sun-Moon-Earth system, and graphs (as the H-R diagram). Moreover, planetariums and science centers offer visitors realistic simulations using software packages such as Celestia, Starry Nights, and Stellarium.

At the same time, astronomy is a content area where students frequently hold a variety of a misconceptions as, for instance that seasons are due to Sun-Earth distance, or that the Moon phases are due to Earth's shadow (Baxter, 1989; Trumper, 2006; Trundle, Atwood, & Christopher, 2002). Some authors have pointed out that the persistence of such alternative conceptions may be partly due to the difficulty of reading and interpreting the images commonly used in school textbooks (Pena & Quilez, 2001; Dove, 2002; Ojala, 1992; Lee, 2010). For this reason, the question that guided this study was as follows*: "Do images and animations about basic astronomical phenomena support or hinder learning of the related scientific content?"*

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2 Review of literature

The increasing use of pictures or graphical representations in science teaching raises the issue of understanding the so-called *"visual language"*, which features functions and structures similar to those of verbal language (Halliday, 1978; Kress & Van Leeuwen, 1996). The knowledge of the visual language is necessary to communicate in an appropriate manner and helps to acquire new information. Still images are the most elementary components of visual language used in the teaching of science. For instance, figurative images (illustrations) representing ideas or scientific concepts are widely used at primary and middle school level. As education advances toward the university level, science communication exploits more schematic and technical images. However, photographs, drawings, and diagrams in school textbooks and academic manuals do not guarantee greater effectiveness in communicating science contents since students need to know how to interpret the visual language of an image so that they can correctly infer its content (Roth, Bowen & McGinn, 1999; Roth, Pozzer-Ardenghi, & Han, 2005). For instance, some studies claim that students consider diagrams more useful than photographs in understanding scientific concepts, since photos may convey also hidden meanings (Kearsey & Turner, 1999; Pozzer-Ardenghi & Roth 2005). Moreover, according to other studies, images sometimes produce an effect contrary to that intended by the authors themselves, undoing the intention of the images in helping the explanation of a concept (Reid, 1990; Reid & Beveridge, 1990). Finally, there is sometimes disparity in visual representation systems (e.g. textbook images as opposed to teacher diagrams and gestures). In the following section, we describe the theoretical framework used in this study to analyze visual representations.

3 Theoretical framework

As evidenced by the above studies, since visual representations do not simply present objects and concepts, students cannot be passive receivers of such representations, rather, they are active interpreters. Written scientific communication is, in general, multimodal (Lemke, 1998), i.e., the visual language necessarily exists alongside with more traditional modalities of communication such as the verbal or the mathematical ones (Kress & Ogborn, 1998; Barlex & Carré, 1985; Jewitt, Kress, Ogborn & Tsatsarelis, 2000). For example, a frequently used modality is the verbal-visual one, where text is accompanied by one or more Cartesian graphs that detail the reported contents (Schnotz, Picard & Hron, 1993). The study of the symbols and signs (semiotics) used in the visual language may be useful in interpreting and predicting student' difficulties when dealing with images in science communication. For this reason, to analyze images and simulations, this study adopted a socio-semiotic theoretical framework inspired by the works by Kress and Van Leeuwen (1996).

The framework categorizes images according to the way in which symbols and signs are organized with the aim of expressing the intended concepts (Lynch, 1988). Two types of visual representational structures, narrative and conceptual, are defined (Figure 1). The narrative representation depicts a sort of *"transaction between participants in a temporary relationships"* and can be *"naturalistic"*, for example a drawing that represents a well-defined time of a day, or *"abstract"*, for example, the isobar curves indicating the weather conditions of a given day.

The conceptual representations may be of three main types: classificatory, analytical and symbolic. The classificatory representations define a relationship or a taxonomy of the represented elements: typical examples are tree diagrams that represent the hierarchical structure of an organization. The analytical representations define a relationship or a part-whole type structure: typical examples are road maps. Symbolic representations define a relationship based on a meaning provided by the reader: typical examples are expressionist paintings or mathematical equations.

The possibility of combining all these different types of representations may generate difficulties in the interpretation of the message(s) expressed in an image. This framework was developed and adopted within the STTIS (Science Teacher Training in an Informa-

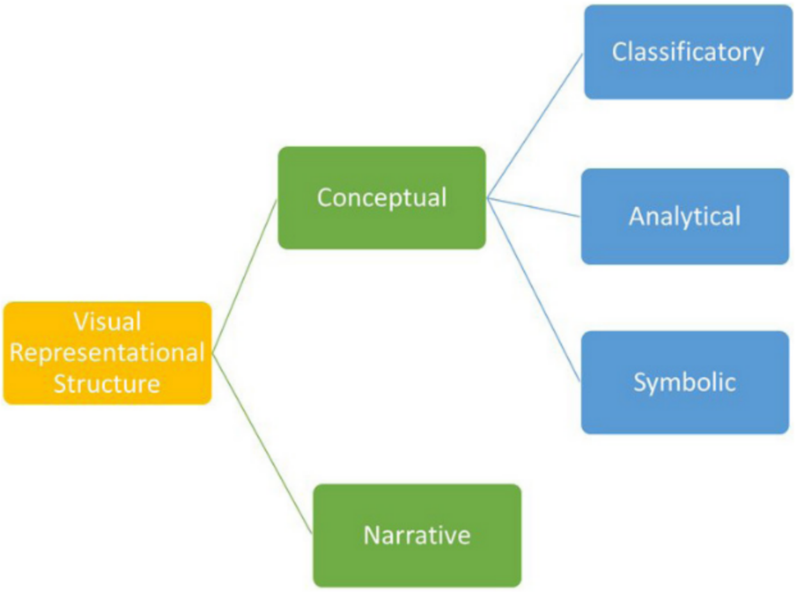

Fig. 1. Types of visual representational structures.

tion Society) project. The results of the research studies carried out during the project (Ametller & Pintò, 2002; Pintó & Ametller, 2002; Stylianidou, 2002), led to the definition of a list of iconic features that may be sources of difficulty when reading and interpreting documents containing different types of visual representations.

The visual features relevant to this study are as follows (adapted from Pintò, 2002, pag. 231-232):

- Elements representing both real world and schematic or symbolic entities (R / S)
- Elements to be selected or conceptually highlighted in relation to textual/graphical features, which do or do not make them salient (SEL)
- Elements requiring appropriate reading of symbols, and which contain examples of synonymy, homonymy and/or polysemy of symbols (SYM)
- Presence/absence of verbal elements to be read as an important part of the image, such as captions (VER)
- Presence of two or more conceptually related images (INT)
- Structures that require the interpretation of the spatial distribution of symbols and signs (CST)

The R/S, SEL, SYM and VER categories represent local iconic features of an image, whose meaning is independent of the specific image in which they are used (for example, the verbal element "m/s" in a Cartesian graph always indicates the measure of speed, regardless of the appearance of the curve represented in the graph). The INT and CST categories represent global iconic features of an image, whose meaning depends on the image in which they are used (for example, specific s (t) and v (t) graphs that refer to the same motion). The above list permitted explanation of well-known difficulties for students in the interpretation of kinematic graphs (Beichner, 1990) and images regarding geometrical optics (Colin, Chauvet & Viennot, 2002). Moreover, the list was useful in analyzing students' difficulties when dealing with real-time experiments (Testa, Monroy & Sassi, 2002). Figure 2 and 3 show the application of the framework to one of the chosen images from the textbook by Palmieri & Parotto (2012) and to one of the two chosen simulations about change of seasons.

Conceptual difficulty	Element of the List
The image emphasizes the ellipticity of the Earth's orbit and could lead to a wrong justification of seasons (Ojala, 1992)	Spatial structure (CST)
The four positions of the Earth, which mark Equinotia and Solstitia, are shown together in the same diagram, even if they refer to different times.	Spatial structure (CST)
Missing indication of the tilt of the Earth's axis, indication of elements that are not important for explaining seasons (days, solstitia line, equinotia lines, aphelion and perihelion)	Verbal Elements (VER)

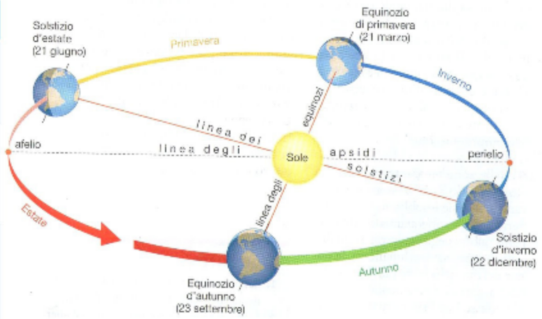

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Fig. 2. Analysis of the textbook image "Seasons".

Conceptual difficulty	Element of the List
Role of the Planet's axis on seasons: need to explicit that the view in the main frame is from outer space	Selection of features (SEL)
Relationships between images of planet' s orbit, the Sun path, the house and the sun's rays	Presence of two or more images (INT)
Sun' s rays represented as parallel arrows in the small frame	Similarity of symbols (arrows, circles, rays) (SYN)
Effects of axis' tilt on planet's temperature represented by a thermometer	Presence of schematic and realistic representations (R/S)

http://highered.mheducation.com/sites/dl/free/007299181x/78778/Seasons_Nav.swf

Fig. 3. Analysis of the simulation "Seasons Navigation".

4 Methods

As a research tool, we adopted 45-minute semi-structured interview in which, for a given textbook image or simulation, students were asked a question about the represented phenomenon. The student could answer the proposed questions with words and drawings, using all information he/she had about the particular phenomenon. The interviewer focused on the iconic features of the image or simulation. Six images and two simulations were used. Two images were about seasons (*Seasons and Sun's rays), two about eclipses (Eclipses, Eclipses Frequency), and two about moon phases (Phases of the Moon, Dark Side of the Moon). The two simulations were about changes of seasons (Seasons Ecliptic, Seasons Navigation). Example question for the simulation "Season Ecliptic"*[1] is reported in Figure 4.

Two groups of students participated in the study. Eighteen students (17-18 years old) who participated in a 12 hour out-of-school activity at the Capodimonte Astronomical Observatory in Naples were interviewed about textbook images (Group 1). Sixteen students (16-17 years old), who participated in eight hour out-of-school activity at the Department of Physics of Naples, were interviewed about simulations (Group 2). Both groups had already studied basic concepts of astronomy before the visits.

1 http://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.swf

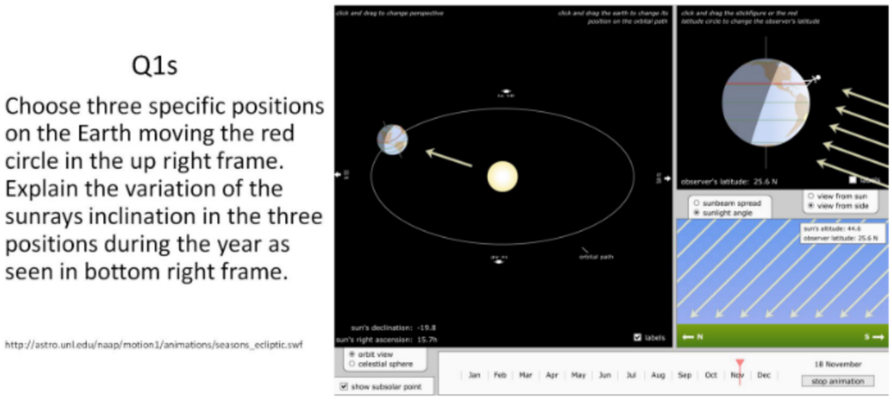

Fig. 4. Example question on simulation "Season Ecliptic".

Image/Simulation	Correct	Not Correct	Total
Seasons	5	13	18
Sun's rays	8	10	18
Eclipses	6	12	18
Eclipses frequency	1	17	18
Phases of the Moon	2	16	18
Dark side of the Moon	3	15	18
Seasons Ecliptic	10	6	16
Seasons Navigation	8	8	16
Total answers	43	197	140

Tab. 1. Distribution of students' answers to the interview.

5 Results

The number of correct and incorrect answers to interview questions is reported in Table 1. The analysis shows that the students encountered many difficulties in interpreting the textbook images. The percentage of correct answers is on average less than 25%. Students had difficulties explaining eclipses and moon phases.

The percentage of correct answers is slightly higher for questions on the simulations about the mechanism underlying the change of seasons.

In the following, we report students' answers about two images (*Seasons, Phases of the Moon*) and one simulation (*Seasons Ecliptic*) that are problematic from the iconic viewpoint.

- Image *Seasons* (Figure 2)

  M3: ...in the Northern Hemisphere it will be summer when the sun's rays are more directed toward the Tropics, it will be summer when the orbit is at the lowest point...
  I: What do you mean by the lowest point of the orbit?
  M3: when we project the ellipse, we have a segment...the highest point represents the maximum distance...
- Image *Phases of the Moon* (Figure 5)

  I: Can you tell me from this image, what phase of the Moon the two observers (red and yellow dots) will see?

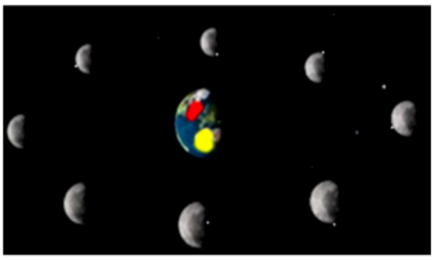

Fig. 5. Image "Phase of the Moon".

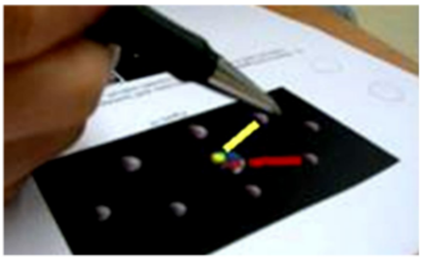

Fig. 6. Students' drawing to answer to a question about the image "Phases of the Moon".

F9: Well, the person indicated by the red dot will see the waning crescent Moon, while the person indicated by the yellow dot will see the waxing crescent Moon
I: So the two persons will see different Moons, right?
F9: Yes, because they have a different Moon on their vision line
I: Can you draw these lines?
F9: sure…the lines connect the dots to the Moons.. (Figure 6)

- Simulation Seasons Ecliptic (Figure 4)

M14: when we are in aphelion, the Sun heats the Earth more…
I: …did you infer this from the image?
M14: No, I already knew it..
I: …so, what happens when you run the simulation?
M14:… Mhhh. I see that when the simulation is running the change of sunrays inclination is due to the change in the velocity of the Earth along the orbit..

I: Does this simulation help you to justify change of seasons?
F1: yes, when we change the observer's position on the Earth, the inclination of the sunrays is different..
I: Ok, I see… but what can you infer from this?
F1: …when I move the Earth along its orbit, the inclination of the sunrays vary, so the same thing is happening… therefore… seasons are due to the motion of the Earth and the inclination of the Earth's axis…
I: Yes… but what is the role of the red circle in the upper right frame?
F1: …it is the parallel on which the observer lies…
I: …is it important the red circle to understand the seasons' phenomenon?
F1: .. I don't know… maybe it is a way to better indicate the observer and his movements on the Earth….

6 Discussion and implications

Results reported in Table 1 show that most of the chosen textbook images did not help students to grasp the represented concept. This finding confirms the difficulties generically pointed out in previous studies about students' alternative conceptions on these phenomena (Oyala, 1992; Pena & Quilez, 2001; Dove, 2002). Furthermore, analysis of the answers provided suggests that students' difficulties in reading and interpreting the proposed images are plausibly linked to specific iconic features of the images, namely the spatial structure (CST), the presence of real/symbolic elements (R/S) and of different images in the same iconic frame (INT). In particular, the spatial structure of the proposed images may have led the students to construct an incorrect or inadequate geometric model of the represented phenomena.

Apparently, students had fewer difficulties when dealing with simulations than textbook images. This evidence likely suggests that the possibility of changing parameters in the simulations may have helped students in the global interpretation of the phenomenon

However, in some cases, the emphasis on the evolution of the phenomenon led to some difficulties in identifying the role of iconic elements of the simulation (SEL).

Overall, iconic difficulties common to textbook images and simulations included:

- contemporary presence of temporal and spatial sequences representing different situations in time and space (e.g., Moon phases or the four seasons represented in the same image);
- differences in visual representation to be represented in the same image or simulation (e.g. the 8 phases of the Moon represented altogether or simulations of the Earth's orbit and sun's rays over seasons)
- the presence of iconic features that represent different scientific ideas or concepts (e.g. curves representing the Moon's orbit and the plane of the orbit represented together) the presence of hidden or implicit graphical features, which should be recognized/identified/selected in order to correctly interpret the image (e.g. the Sun not present in the Moon phases schema or in the sun's rays frame of the seasons simulations);

In general, our findings suggest that in teaching astronomy, teachers should take into account students' difficulties when viewing textbook images and when exploiting interactive simulations. We suggest teachers better characterize the use of simulations, refine their educational goals and integrate them with the widely used textbook images. In this way, multiple representations with particular features may be integrated to offer different perspectives that could be coordinated to improve students' learning outcomes. Similarly, since science understanding involves multiple, multi-modal representation and coordination, astronomy education should stress the relationships between visual representations and other semiotic resources (e.g., teacher's gestures).

In conclusion, this study may be a useful starting point for researchers who are involved in designing academic courses in astronomy based on printed images and simulations, such as those used in programs like Stellarium and Celestia.

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