Comparing international and national science assessment: what we learn about the use of visual representations

KYRIAKI ANAGNOSTOPOULOU[1], VASSILIA HATZINIKITA[1], VASILIA CHRISTIDOU[2]

[1]Hellenic Open University
School of Humanities
Greece
hatzinikita@eap.gr
Kellyan@ath.forthnet.gr

[2]University of Thessaly
Department of Early Childhood Education
Greece
vchristi@uth.gr

ABSTRACT

Within the research community in science education, there has been a tendency to show limited interest in examining PISA results with reference to the national context of participating countries although this approach can give valuable insight into a country's students' achievement. Since the interpretations of PISA results could be based on a thorough analysis of the actual items used in international and national contexts, the main issue addressed in this study is to compare PISA test items with assessment tasks used in the Greek school context. 281 PISA science test items as well as 947 assessment tasks included in science school textbooks and 4,248 science examination test items in Greece, were analysed in regard to the frequency of inclusion, the type and the functional role of visual representations within this assessment tasks. The results demonstrate that while PISA test items use visual material in order to communicate scientific information in everyday life contexts by means of specialised graphs and photographs of familiar entities, schooling does not familiarize Greek students with visual representations widely used in science and embedded in real-life situations.

KEYWORDS

PISA, Science, test items, school-based examinations, textbooks, visual representations, functional role, type

RÉSUMÉ

Au sein de la communauté de recherche en didactique des sciences, il y a la tendance de montrer un intérêt limité à examiner les résultats de PISA en rapport avec le contexte national des pays participants bien que cette approche puisse nous faire mieux comprendre les performances des élèves du pays. Étant donné que l'interprétation des résultats de l'enquête PISA pourrait être basée sur une analyse approfondie des items actuels utilisés dans des contextes internationaux et nationaux, l'objectif principal de cette étude sera la comparaison des items de culture scientifique de PISA avec les tâches d'évaluation utilisées dans le contexte scolaire grec. 281 *items de culture scientifique de PISA ainsi que 947 tâches d'évaluation inclues dans les manuels de sciences et 4248 items des tests de Sciences des examens scolaires grecs ont été analysés en ce qui concerne la fréquence d'inclusion, le type et le rôle fonctionnel des représentations visuelles au sein des tâches d'évaluation. Les résultats démontrent qu'alors que les items de culture scientifique de PISA utilisent du matériel visuel afin de communiquer des informations scientifiques dans un contexte de vie de tous les jours par le biais des graphiques spécialisés, et des photos d'entités familières, l'école grecque ne familiarise pas les élèves grecs avec les représentations visuelles largement utilisées dans les sciences et incorporées dans des situations de la vie réelle.*

MOTS CLÉS

PISA, Science, test items, examens scolaires, manuels, représentations visuelles, rôle fonctionnel, type

INTRODUCTION

The OECD-led Program for International Student Assessment (PISA) is one of the largest-scale international assessments, aiming to perform, every three years, a cross-national assessment of the reading, mathematical and scientific literacy of 15-year-old students. The PISA literacy frameworks as well as the assessment test items are not constructed on the basis of common curricular elements of the participating countries, but on the essential knowledge and skills needed in further adult life.

As PISA provides rich data for analysis at both international and national levels, a general research trend in this area is to develop secondary analysis of PISA-generated datasets in order to explore contextual factors related to students, schools and educational systems that might be associated with students' achievement (e.g. Fuchs & Wößmann, 2007; Chiu & Xihua, 2008). However, "the main value for participating countries in PISA is found only when the results are examined with reference to the national context" (Oldham, 2006, p. 27) since this line of research could provide a more comprehensive understanding of students' achievement in relation to a country specific educational system (e.g. Von Collani, 2001; Simola, 2005).

Greece has participated in PISA since its inception in 2000 and Greek students performances have been significantly below the OECD average in all PISA cycles and all subject areas (OECD, 2001, 2004, 2007, 2010, 2014). This poor performance of Greek students is a matter of concern while it appears that they do not handle relevant knowledge and skills to produce appropriate answers.

Probably the Greek curriculum and teaching-learning culture have been unsuccessful in familiarising students with test items that involve real-life situations, modelling, or problem-solving approaches, which are the focus of the PISA assessment. This hypothesis has been informed by the Bernsteinian framework -specifically the closely interlinked recognition and realisation rules that decisively influence the way students respond to assessment tasks (Bernstein, 1996)- and its empirical evidence (e.g. Morais & Antunes, 1994; Morais & Miranda, 1996; Cooper & Dunne, 2000).

Evaluation plays a prominent role on the teaching-learning culture. Therefore studies comparing science assessment tasks that students are conditioned to address in specific national contexts with PISA science assessment tasks -international context- could illuminate students' achievements in PISA.

There is a growing body of research focused on the relation between specific characteristics of PISA science test items and students' achievement (e.g. Nentwig et al., 2009; Le Hebel, Tiberghien & Montpied, 2014). However, research exploring the PISA framework and test items with reference to national contexts and especially to national curricular elements and textbooks is fairly limited (e.g. Shiel, Sofroniou & Cosgrove, 2006; Oldham, 2006; Hatzinikita, Dimopoulos & Christidou, 2008; Pinto & El Boudamoussi, 2009; Dolin & Krogh, 2010; Anagnostopoulou, Hatzinikita & Christidou, 2012; Anagnostopoulou, Hatzinikita, Christidou & Dimopoulos, 2013).

VISUAL REPRESENTATIONS

Learning the specialised language of science has been considered as an important objective for science education (e.g. Halliday & Martin, 1993; Norris & Phillips, 2003). The natural language of science is an integration of texts, visual representations (i.e. diagrams, pictures, graphs, maps, tables, charts) and mathematical expressions (i.e. equations) (Lemke, 1998). Text, mathematics and visual representations are needed to represent abstract and complex scientific concepts and explanations, since the capacity of verbal language to describe them is very limited (e.g. Prain, Tytler & Peterson, 2009).

Visual representations are considered to play an important role in learning and understanding science. Different representational systems offer different levels or types of information that could support students' development of scientific understandings (Kozma et al., 1996; Ainsworth, 1999). Moreover, visual representations allow students to visualize relationships between different concepts and enhance the development of deeper understanding of scientific phenomena (Wu, Krajcik & Soloway, 2001; Treagust, Chittleborough & Mamiala, 2003). Besides, scientific representations based on graphs can be used as reasoning tools for making predictions or drawing conclusions (e.g. Stern, Aprea & Ebner, 2003; Yore & Treagust, 2006).

Furthermore, one major goal of science education is to promote the development of scientific literacy in order to enable pupils to effectively participate in a largely science- and technology-driven society (McClune & Jarman, 2011), putting new and increased demands on our capacity to represent, manipulate and decode information in visual forms (Lowrie & Diezmann, 2007). "Being 'graphicate' is becoming an important part of everyday knowledge, equal in status to being literate and numerate" (Åberg-Bengtsson & Ottosson, 2006, p. 43-44).

Consequently, non-verbal processing of information, such as interpretation of graphs, maps and drawings, is necessary in educational contexts as well as everyday life (Åberg-Bengtsson, 1999) since students are required to make sense of visual representations in both school and out-of-school contexts.

As school systems attempt to provide learning opportunities for students to acquire knowledge, skills and processes that equip them to function in society, visual and spatial reasoning become increasingly important and valued. Students need to understand and conceptually link different representational modalities or forms in learning science and in learning how to think and act scientifically (e.g. Lemke, 1998; Ainsworth, 1999).

In view of this requirement there has recently been a considerable shift towards increasingly using visual representations to assess students' knowledge in schools (Lowrie & Diezmann, 2009).

The importance of representational competences is also emphasised in the PISA framework, according to which scientifically literate individuals can comprehend and interpret scientific evidence and data in order to make claims and draw conclusions (OECD, 2013). This competency -explicitly assessed in the PISA science domain- requires students to interpret evidence presented in various representation forms, including diagrams or other visual representations; to use mathematical tools to analyse or summarise data; and to transform data to different representations (OECD, 2006, 2013).

Considering the crucial role of visual representations in learning science in general and in scientific literacy in particular, several studies have suggested that students' ability to interpret and produce visual representations, is important for success in standardised science tests and has a strong influence on students' achievement (e.g. Schnotz, Picard, & Hron, 1993; Wu & Shah, 2004; Yeh & Mc Tigue, 2009).

The interpretation of visual representations is a context-dependent skill, and the translation from an unfamiliar graph to verbal descriptions is a demanding task even for scientists who are not familiar with the subject matter (Roth & Bowen, 2001; Roth & Lee, 2004). Indeed, visual representations can often make the task more difficult to accomplish (e.g. Berends & van Lieshout, 2009). The degree of difficulty students experience with a visual representation depends on the visual representation itself and on students' familiarisation with it. The capacity to decode information in a task determining students' performance, is influenced -among other factors- by the properties of visual representations (e.g. Salomon, 1994; Brna, Cox, & Good, 2001), that is their type, mode and function (e.g. Mayer, 1997; Schnotz & Bannert, 2003; Stern, Aprea, & Ebner, 2003; Schnotz & Kürschner, 2008).

In regard to PISA assessment, visual representations included in science test items could affect students' performance. PISA units assessing scientific literacy have a common structure: a stimulus material which may include text and visual representations (tables, graphs, photographs, etc.) accompanied by questions (test items) associated to the stimulus material. This unit structure is considered to simulate realistic contexts and reflect the complexity of everyday situations (OECD, 2006).

AIM OF THE STUDY

As already mentioned visual representations and students' familiarisation with them influence their achievement in science assessment tasks.

In order to elucidate our understanding of Greek students' low achievement in PISA with reference to the national context, a study comparing visual representations included in science textbooks' assessment tasks and school-based examinations, and PISA science test items seems meaningful.

Thus, the aim of this study is to reveal possible convergences and divergences related to the frequency of inclusion of visual representations, their type, and their functional role between the Greek school system and PISA, respectively.

School textbook assessment tasks and school-based examination items are the most crucial materials for illuminating the assessment discourses the students become familiar with at school, since they are considered as points of reference to the national context.

More particularly, the Greek educational system is particularly centralized (e.g. a unique school textbook is prescribed for mandatory use by all schools). Therefore, science textbooks as well school-based examinations play a dominant role in the educational process, widely determining classroom practices.

METHOD

Sample

The sample of this study consists of: (a) 281 PISA test items from all cycles used between 2000-2012 for assessing scientific literacy in both PISA field trials and main studies, (b) 947 assessment tasks included in lower secondary science school textbooks currently in use (343 biology assessment tasks intended for 7th and 9th grade Greek students, 425 physics and 179 chemistry, intended for 8th and 9th grade Greek students)[1] and (c) 4,248 biology, physics and chemistry examination[2] test items in Greece, nationally representative. More specifically, the 4.248 examination items involved 1,359 biology, 1,476 physics, and 1,413 chemistry test items used at the end-of-year advancement and discharge examinations, in the period covering the school years between 2007-2008 and 2011-2012.

All visual material included in the three abovementioned datasets were analysed. Each visual representation was considered as a single unit of analysis. According to this procedure, three samples of 141, 235 and 858 visual representations from PISA test units, school science textbooks assessment tasks, and examination test items respectively, were collected and analysed.

Analysis framework and procedure

Initially, the frequency of visual representations in different assessment settings was recorded. Then, taking into account the characteristics of the visual material considered to be associated with students' performance (see section 'Visual representations'), a content analysis of the sampled visual representations was conducted on the basis of a two-tiered framework. This framework consisted of the following axes of analysis, along with their distinct categories:

(i) *Type of visual representations*. The classification of visual representations was based on Moline's (1995) categorisation system, modified according to the needs of this study. The different types of visual representations identified, along with their short description are presented in Table 1.

(ii) *Functional role of visual representations*. The following three-levelled scale proposed by Yeh & Mc Tigue (2009) was adopted in order to analyse visual representations regarding their functional role:

- Level 1: At the lowest level, a visual representation displays redundant information to the questions themselves. Such representations are deemed unnecessary for answering the question because, without the representational support, the question could still be answered correctly (see for example Figures 1, 2).
- Level 2: At this level, a visual representation provides partial information that is necessary, but not sufficient, for answering the question. That is, students need to derive information from the visual representation, the verbal text, and their prior knowledge in order to complete the task (see for example Figures 3, 4).

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[1] In Greece physic and chemistry are taught at the 8th and 9th grades while biology at the 7th and 9th grades.

[2] In Greece at the end of the school year students participate in advancement examinations (for the 7th grade and the 8th grade) and discharge examinations (for the 9th grade, which corresponds to their last year of compulsory education). Both examinations are school-based.

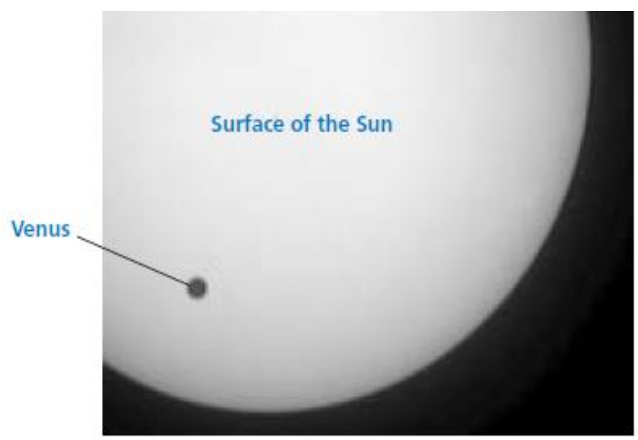
- Level 3: A visual representation of this level contains all necessary information for answering the question. The students have to interpret and reorganize the information in order to answer the question. However, they don't rely on their prior knowledge, but instead they need procedural knowledge (see for example Figures 4, 5).

TABLE 1

Classification of visual representations according to their type

Type	Definition
Photograph	Photograph of a subject or scenery
Naturalistic Drawing	All features of the subject are depicted in detail
Picture Glossary	Parts of the pictures are named with labels
Flow Chart	Arrows or numbers are marked among stages
Map	Geographic features, like mountains or buildings, are marked to show spatial relation to others
Table	Tables are composed of cells
Graphs (diagrams, histograms)	Quantity information is recomposed in the format of relative graphs
Cutaway exhibitions	Internal parts or processes are marked with labels
Stylized Drawing	Graphics are delineated only with the outlines or in a symbolic drawing

FIGURE 1



QUESTION 30.1

Why was the transit observed by projecting the image onto a white card, rather than by looking directl through the telescope?

A. The Sun's light was too bright for Venus to show up.

B. The Sun is big enough to see without magnification.

C. Viewing the Sun through a telescope may damage your eyes.

D. The image needed to be made smaller by projecting it onto a card.

Level 1 visual representation in a PISA science test item (OECD, 2009, 245)

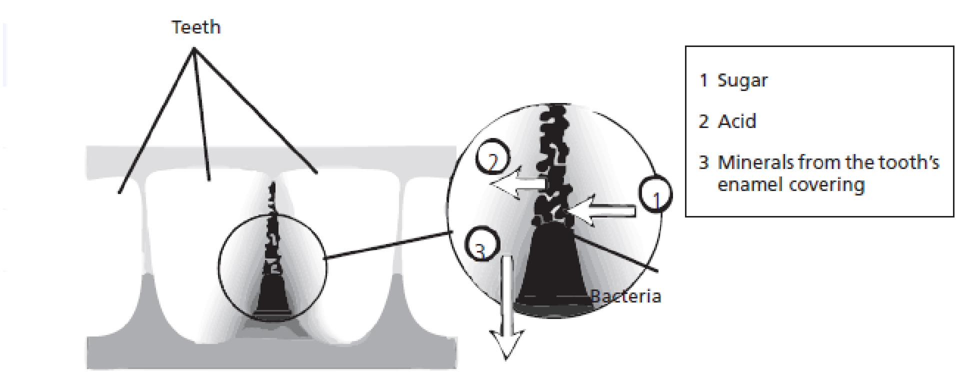
FIGURE 2

Complete the following table by marking the appropriate column with a (+):

	PLANT CELL	ANIMAL CELL
Nucleus		
Cytoplasm		
Plasma membrane		
Mitochondrion		
Cell wall		
Chloroplast		
Vacuole		

Level 1 visual representation in a school science textbook assessment task (Mavrikaki, Gouvra & Kampouri, 2009, 25)

FIGURE 3



QUESTION 20.1

What is the role of bacteria in dental caries?

E. Bacteria produce enamel.

F. Bacteria produce sugar.

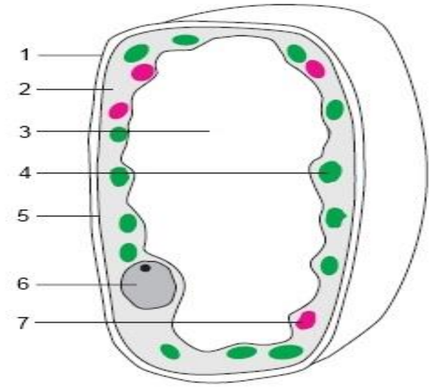
G. Bacteria produce minerals.

H. Bacteria produce acid.

Level 2 visual representation in a PISA science test item (OECD, 2009, 224)

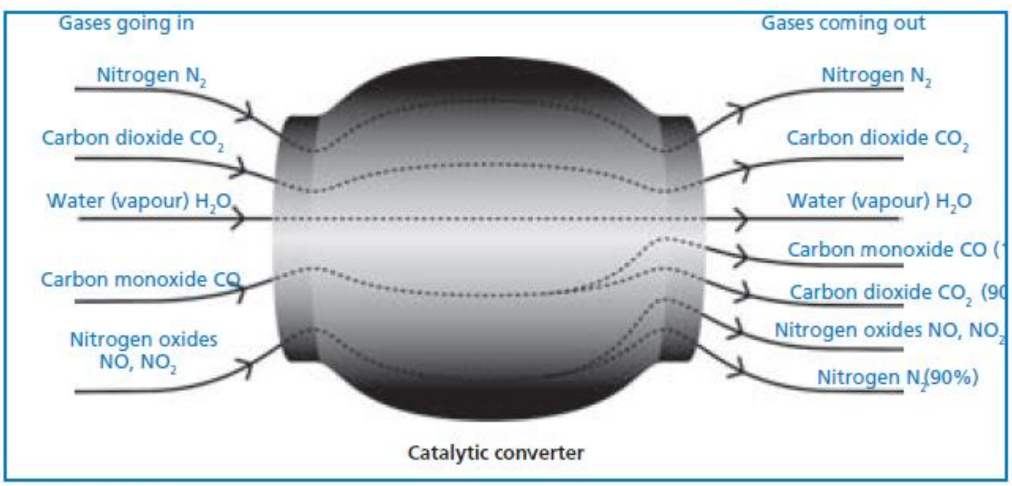
FIGURE 4

The figure at right illustrates a eukaryotic cell. Complete the indications correctly using the following terms: mitochondrion, nucleus, chloroplast, cell wall, plasma membrane, vacuole, cytoplasm. Is this an animal, or a plant cell? Explain your answer.



Level 2 visual representation in a school science textbook assessment task (Mavrikaki, Gouvra & Kampouri, 2009, 24)

FIGURE 5



QUESTION 32.1

Use the information in the diagram above to give *an example* of how the catalytic converter makes exhaust fumes less harmful.

....

....

Level 3 visual representation in a PISA science test item (OECD, 2009, 248)

FIGURE 6

The following table illustrates the energy (in kJ) included in 100g of some aliments that we consume every day. Columns A, B, C and D indicate (without matching) the percentage of proteins, fat, carbohydrates and water, that is contained in each of the aliments. Observe the table and answer the following questions.

FOOD	Energy (kJ)	A (%)	B (%)	C (%)	D (%)
Milk	290	3	89	4,5	3,5
Butter	3.000	0,5	16,5	-	83
Potatoes	370	2	82	16	-
Beef	1.300	25	55	-	20
Tuna	700	18	70	-	12

a) Which aliment contains the highest and which the lowest amount of energy?
b) Which of the columns A, B, C and D illustrates the concentration of proteins, fat, carbohydrates and water? Explain your choices.

Level 3 visual representation in a school science textbook assessment task (Mavrikaki, Gouvra & Kampouri, 2009, 54)

Analysis of the visual material was independently performed by two of the authors and arrived at an inter-rater agreement of at least 92% for each dimension, while discrepancies were discussed and resolved with the contribution of the third author.

RESULTS

In this section, the results of the analysis of the visual material included in the PISA test items are presented and discussed in comparison with corresponding results concerning the assessment tasks in the Greek science textbooks and school-based examinations. These results are also presented in Table 2, along the different dimensions of the analysis framework.

Frequency of inclusion of visual representations
Almost half of the analysed PISA test items (50.2%) comprise visual representations while assessment tasks in science school textbooks and examinations' items use visual representations less frequently (24.8% and 20.2% respectively).

Type of visual representations
In regard to the type of visual representations, it seems that visual material in PISA and school-based examination items primarily involve stylized drawings (30.5% and 43.2% respectively) while in Greek science textbooks there is a preference to tables (27.7%) over other categories. Tables are also quite frequently used in PISA items (17.7%) and examination test items (26%). Moreover, it is worth mentioning the recorded differences in the use of graphs (diagrams and histograms): graphs are common in PISA test items (24.8%) but less frequently used in the school science context (16.2% and 7.2% in examination items and school textbooks correspondingly).

Besides, detected statistically significant associations reveal the following tendencies. PISA test items tend to comprise graphs, stylised drawings, but not tables, while the assessment tasks in science textbooks do not favour the use of graphs (χ^2=77.98, df=9, p<0.001).
In addition, PISA favours the use of photographs -while school-based examinations items do not- and the inclusion of graphs in assessment tasks (χ^2=115.67, df=9, p<0.001).

TABLE 2

Visual representations in PISA and school-science assessment in Greece

	PISA		Greek school science context			
			Assessment tasks in science school textbooks		School-based science examination test items	
	N	Percentage	N	Percentage	N	Percentage
Frequency of visual representations' inclusion						
Number of visual representations included in items	141	50.2%	235	24.8%	858	20.2%
Type of visual representations						
Photograph	18	12.8%	19	8.1%	4	0.5%
Naturalistic drawing	4	2.8%	35	14.9%	25	2.9%
Picture glossary	5	3.5%	5	2.1%	5	0.6%
Flow chart	3	2.1%	8	3.4%	26	3.0%
Table	25	17.7%	65	27.7%	223	26.0%
Graph (diagram/histogram)	35	24.8%	17	7.2%	139	16.2%
Cutaway exhibition	6	4.3%	27	11.5%	41	4.8%
Stylized drawing	43	30.5%	28	11.9%	371	43.2%
Map	1	0.7%	0	0.0%	0	0.0%
Hybrids	1	0.7%	31	13.2%	24	2.8%
Functional role of visual representations						
Level 1	37	26.2%	99	42.1%	317	36.9%
Level 2	39	27.7%	114	48.5%	475	55.4%
Level 3	65	46.1%	22	9.4%	66	7.7%

Functional role of visual representations
In terms of function the majority of PISA test items' visual material (46.1%) contain all necessary information for answering the question (level 3), a tendency not frequently identified in the school science assessment context (see Table 2). Visual representations in assessment tasks in school science textbooks and in examination test items either contain insufficient information for answering the question (level 2: 48.5% and 55.4% respectively) or play a decorative role, i.e., they don't provide any information (level 1: 42,1% and 36.9% correspondingly). The aforementioned differences are statistically significant: PISA items tend to comprise level 3 visual representations more frequently than expected when compared to science textbook assessment tasks ($\chi2$=66.97, df=2, p<0.001), and also when compared to school-based examination items ($\chi2$=158,2, df=2, p<0.001). Level 3 representations tend not to be used in the Greek assessment context, in which Level 1 or 2 representations are preferred.

DISCUSSION

The results presented in the previous section indicate interesting divergences between PISA test items and school-based assessment tasks in regard to the visual material they include. Specifically, PISA test items significantly rely on the visual mode, while assessment tasks in Greece (science school textbooks and school-based examinations) comprise visual material to a lesser extent. Graphs (e.g. diagrams, histograms), a powerful tool for communicating scientific concepts and explanations, tend to be used in PISA assessment tasks more frequently than in assessment tasks included in science school textbooks and examination items. In addition, PISA test items tend to favour the use of photographs, but this is not the case in school-based examination items. The above mentioned differentiations concerning preference of graphs and photographs in PISA items might be associated with PISA's explicit orientation towards scientific literacy, i.e. students' capacity to extrapolate from what they have learnt and apply their knowledge in novel contexts. Firstly, graphs play a significant role in assessing students' ability to transfer knowledge and skills acquired at school to novel settings; they can bridge the gap between everyday knowledge -based on verbal description- and scientific formalism -conveyed by mathematical formulas- and can therefore be used as tools for knowledge transfer (Stern, Aprea & Ebner, 2003; Yore & Treagust, 2006). Secondly, photographs are realistic representations necessary to introduce the everyday life context, an imperative element in the PISA scientific literacy assessment.

Beside the frequent use of visual material and the predominant role of graphs and photographs, the importance of visual material in PISA assessment is also highlighted by its functional role. The visual representations included in PISA test items, contrary to school-based assessment items, tend to comprise all necessary information for answering the question (level 3). Thus, while PISA test items use visual material in order to communicate scientific information in everyday life contexts by means of specialised graphs and familiar entities' photographs respectively, schooling does not familiarize Greek students with visual representations widely used in science and embedded in real-life situations.

Research on the effect of visual representations on students' understanding and achievement have revealed students' lack of attention to graphics as compared to text, and also their inability to utilize information from graphics (Mc Tigue & De Croix, 2010). Mathai and Ramadas (2009) state that students heavily rely on the verbal mode when they cope with assessment tasks involving both text and graphs, and that they demonstrate low tendency to use diagrams.

Considering that students' achievement is related to their familiarization with the context and the properties of a test item (Morais & Abtunes 1994; Salomon, 1994; Morais & Miranda 1996; Cooper & Dunne 2000; Brna, Cox, & Good, 2001; Yeh & Mc Tigue, 2009), it could be argued that if students are already familiarised with visual representations of particular types and functions, then they could understand and successfully cope with required tasks that incorporate representations with these familiar characteristics.

Therefore taking into account the crucial role of evaluation in school practices in Greece, as well as the lack of attention to the visual component in the school-based assessment context, and the divergences depicted in this study between PISA science items and assessment tasks in the school science context, it comes as no surprise that Greek students face difficulties in interpreting and producing appropriate meanings when faced with PISA assessment tasks. They are not acquainted with relying on visual representations in order to extract information for answering test items. Thus, the actual information embedded within a given graphics task is not likely to be influential in their answer. This inadequacy in handling (specialised) visual representations could be related to Greek students' low achievement in PISA. This is also in accordance with the PISA 2006 results, in which Greek students scored lower in the competency "using scientific evidence" (i.e. "draw conclusions based on the evidence presented in various representation forms") than in any other competency assessed in PISA scientific literacy test (OECD, 2007).

In a visually-oriented society, greater attention should be given to the practices of reading, producing and understanding visual representations (Roth, 2002). Educational researchers (e.g. Pea, 1994; Roth & McGinn, 1998) call for an increased attention to the use of visual representations in education in general and in science education in particular.

The intention is to establish learning environments that support students in becoming literate in practices related to reading, producing and using visual representations. This entails shifting from a science education founded on a predominantly verbal characterisation of learning and thinking (Ramadas, 2009), emphasising verbal- and algebraic thinking (e.g. Trumbo, 2006), to a science education focused on developing expertise in using visual modes in the science classroom.

Since visual literacy is considered as a crucial component of scientific literacy, it is essential for science teaching and learning to familiarise students with the visual component of scientific language and teach them how to interpret, integrate and reproduce visual representations. The findings of this study could contribute to this endeavour.

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This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund