Analysis of Cell Representations Included in Greek Biology School Textbooks

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Abstract

The cell is the basic structural and functional unit of all living organisms. It is a basic concept for understanding biological and life phenomena in general, so it is studied in all educational levels. In the present work, the visual representations related to the cell which are included in the Greek biology school textbooks taught in primary and secondary education were collected and analyzed following a recently proposed three-dimensional (3D) classification scheme which involves the following axes: abstractness, function, and level of the representation. The degree of abstractness of each visual representation was characterized by five categories namely Iconic Diagram, Visual Diagram, Verbal Diagram, Quantitative Representation and Hybrid. The function of the representation was described by six categories namely Decorative, Depictive, Deconstructive, Classificational, Explanative, and Mixed. Finally, the level of each representation was characterized as either Macroscopic, Microscopic, Submicroscopic, Symbolic or Multiple. A total of 347 visual representations of the cell were found in 14 textbooks of four different educational levels, according to following distribution: 26 in primary school, 83 in lower secondary school, 113 in general upper secondary school and 125 in vocational upper secondary school. With regard to the three dimensions used for the analysis, a statistically significant different distribution is observed among the four educational levels. In the textbooks of primary and vocational upper secondary school the least abstract iconic diagrams dominate, while in those of lower and general upper secondary school the iconic diagrams and visual diagrams are present in similar frequencies. The depictive function is the one most frequently encountered in the primary and vocational upper secondary education textbooks, while in the other two educational levels three functions - namely depictive, deconstructive and explanative - are present in similar frequencies. The microscopic representations of the cell are dominant (> 70%) in the textbooks of primary and vocational upper secondary schools. In lower and general upper secondary school, the microscopic level remains the most popular, but the symbolic and submicroscopic cell representations appear in quite elevated percentages as well (ranging between 13,3% and 28,9%).

Keywords: *cell visual representations, biology textbooks, abstractness of representation, function of representation, level of representation.*

1. Introduction

Biology is taught in all educational levels of the Greek educational system. The cell is a concept which is examined in the majority of the Greek science/biology school textbooks. Its wide presence is due to the fact that it is the basic structural and functional unit of life. The cell as a theme of study, is characterized as difficult to understand by students at different educational levels. Efforts for overcoming this difficulty involve the use of a large variety of visual representations related with different aspects of the cell within school science textbooks [1]. Cell shape, structure and function are represented in different categories of visual representations contributing to a more effective learning process [2].

Recently, a review of the classification systems employed for the characterization of visual representations of biological entities led to the proposal of a three-dimensional classificational scheme [3], according to the following three criteria: degree of abstractness, function and level of each visual representation.

The degree of abstractness is related to the amount of information that can be incorporated in a representation and its degree of similarity to the actual physical object or phenomenon depicted. The degree of abstractness was characterized by five categories namely Iconic Diagram, Visual Diagram, Verbal Diagram, Quantitative Representation and Hybrid. The first four categories are reported with an increasing degree of abstractness; the first category (iconic diagram) refers to representations with a larger resemblance to the physical reality while the fourth (quantitative representation) involves the highest level of abstractness. A fifth category (Hybrid) was used in order to refer to mixed representations which include elements that are assigned to at least two of the first four categories.

The function that a visual representation is intended to serve was described via the following six categories: Decorative, Depictive, Deconstructive, Classificational, Explanative, and Mixed. The first category, decorative, refers to representations that are not connected with the text and do not support it in any meaningful manner. The next two categories, depictive and deconstructive, refer to visual representations which are closely connected with the text and add an element of concreteness. More specifically, a depictive representation is used in order to simply present an entity without additional explanations or labeling, while a deconstructive representation is used for portraying the components of an entity. The fourth category, classificational, refers to visual representations that depict a taxonomy or present the organizational relationships between distinct entities. The fifth category, explanative, refers to graphics that provide more information relative to the fourth category (classificational) by depicting (often via the use of arrows) causal or logical sequences, or active processes which involve change. Finally, a sixth category named "mixed", refers to visual representations that are more complex and contain elements which serve a combination of more than one (usually two) of the last four functions described above (ie. depictive, deconstructive, classificational and explanative).

The criterion related to the level of the visual representation refers to the organization of the graphics according to their spatial dimension in combination with their mode of observation (physical or non-physical). The following five categories were employed in order to describe the level of each visual representation: Macroscopic, Microscopic, Submicroscopic, Symbolic and Multiple. The macroscopic level refers to biological entities which are visible to the naked eye. The microscopic level refers to entities that are visible only under some type of microscope while the submicroscopic refers to representations of macromolecules (eg. DNA, proteins) that may be "visualized" via specialized analytical techniques (eg. NMR spectroscopy, X-ray crystallography). The symbolic level refers to explanatory mechanisms of phenomena which are "observable" via non-physical means (eg. symbols, formulas, chemical equations, metabolic pathways, etc).

This study aims on one hand to explore which are the characteristics of the visual representations of the cell that are found in the Greek biology textbooks of primary and secondary education and on the other to examine whether the types of the representations (as characterized via their degree of abstractness, function and level) are differentiated between the four distinct educational structural levels studied (primary school, lower secondary school, general upper secondary school, vocational upper secondary school).

2. Methodology

The first part of this work involved a systematic search of all biology textbooks taught in the primary and secondary schools in Greece for visual representations related with the concept of the cell. A total of 14 textbooks were investigated with the following distribution among four educational levels: 2 in primary school (Grades 5-6), 3 in lower secondary school (Grades 7-9), 2 in general upper secondary school (Grades 10-12) and 7 in vocational upper secondary school (Grades 10-12).

Subsequently, each visual representation was examined in relation to the three-dimensional classification scheme described in the Introduction and was characterized by a unique set of three categories namely one corresponding to its degree of abstractness, one to its function and one to its level.

Statistical tests (Pearson chi-square) were employed in order to test for statistically significant differences regarding the types of the cell representations between the four educational levels.

3. Results

A total of 347 visual representations of the cell were found in the 14 textbooks examined, with the following distribution among educational levels: 26 in 2 textbooks of primary school (7,5% of total, 13,0 representations per textbook), 83 in 3 textbooks of lower secondary school (23,9% of total, 27,7 representations per textbook), 113 in 2 textbooks of general upper secondary school (32,6% in total, 56,5 representations per textbook) and 125 in 7 textbooks of vocational upper secondary school (36% of total, 17,9 representations per textbook). It is thus deduced that the cell representations appear with the following order of relative frequency:

Upper secondary school > Lower secondary school > Vocational upper secondary school > Primary school

Therefore, the higher educational school level is accompanied by a higher number of visual representations per textbook with the exception of vocational upper secondary school which is more similar to primary school. This fact may be connected with the special nature of this school type which prepares students for careers which are mostly related with technical professions.

With regard to the degree of abstractness, the 347 visual representations of the cell are distributed in four categories as follows: 209 iconic diagrams (60,2%), 108 visual diagrams (31,1%), 2 verbal diagrams (0,6%) and 28 hybrids (8,1%). No quantitative representations were found. These results show the domination of the least abstract visual representations of the cell (ie iconic diagrams such as photographs, technical images, or drawings) in the whole sample. The examination of the distribution within each specific educational level is shown in the following figure (Figure 1).
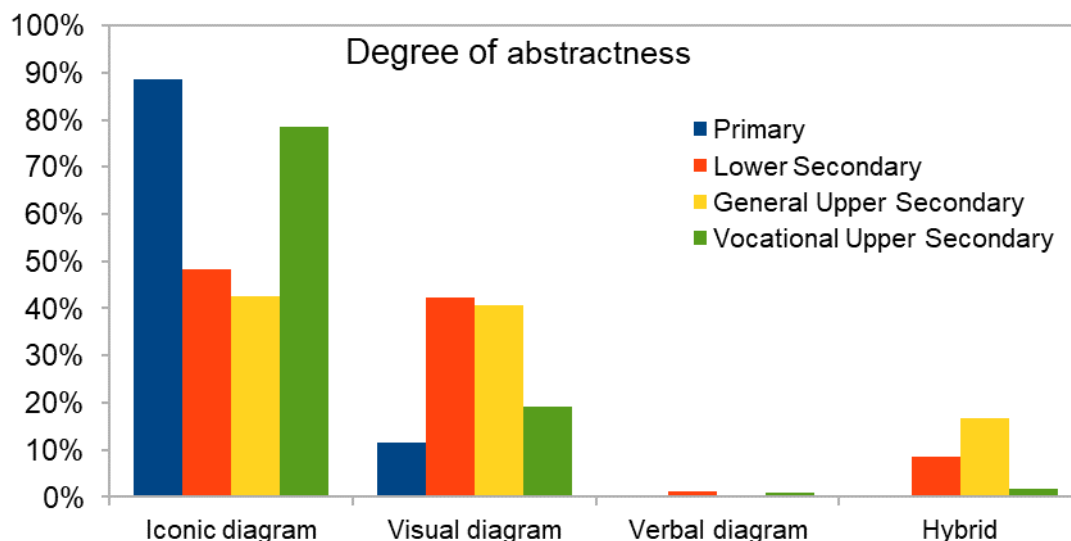

Figure 1: Distribution of visual representations of the cell among the four examined educational levels according to their degree of abstractness

Based on the degree of abstractness, strong evidence is provided for a statistically significant different distribution between the four educational levels (Pearson Chi-Square=54,487, df=9, $p<0.001$). In fact, as shown in Figure 1, the iconic diagrams are dominant in the textbooks of primary and vocational upper secondary schools (88,5% and 78,4% respectively), while in those of lower and general upper secondary school the iconic and visual diagrams are present in similar frequencies (ranging between 40,7% and 48,2%).

With regard to the function intended to serve, the 347 visual representations of the cell are distributed in six categories as follows: 15 decorative (4,3%), 135 depictive (38,9%), 86 deconstructive (24,8%), 38 classificational (11,0%), 67 explanative (19,3%) and 6 mixed (1,7%). The examination of the distribution within each specific educational level is shown in the following figure (Figure 2).

Based on the function of the representation, strong evidence is provided for a statistically significant different distribution between the four educational levels (Pearson Chi-Square=63,162, df=15, $p<0.001$). In fact, as shown in Figure 2, the depictive function is the one most frequently encountered in the primary and vocational upper secondary school textbooks (with percentages 73,1% and 51,2% respectively), while in the other two educational levels three functions - namely depictive, deconstructive and explanative - are present in similar frequencies (ranging between 25,7% and 31,9%).

With regard to their level of representation, the 347 cell graphics are distributed in five categories as follows: 12 macroscopic (3,5%), 190 microscopic (54,8%), 50 submicroscopic (14,4%), 68 symbolic (19,6%) and 27 multiple (7,8%). These results show the dominance of the microscopic representations of the cell in the whole sample. The distribution within each specific educational level is exhibited in the following Figure 3.
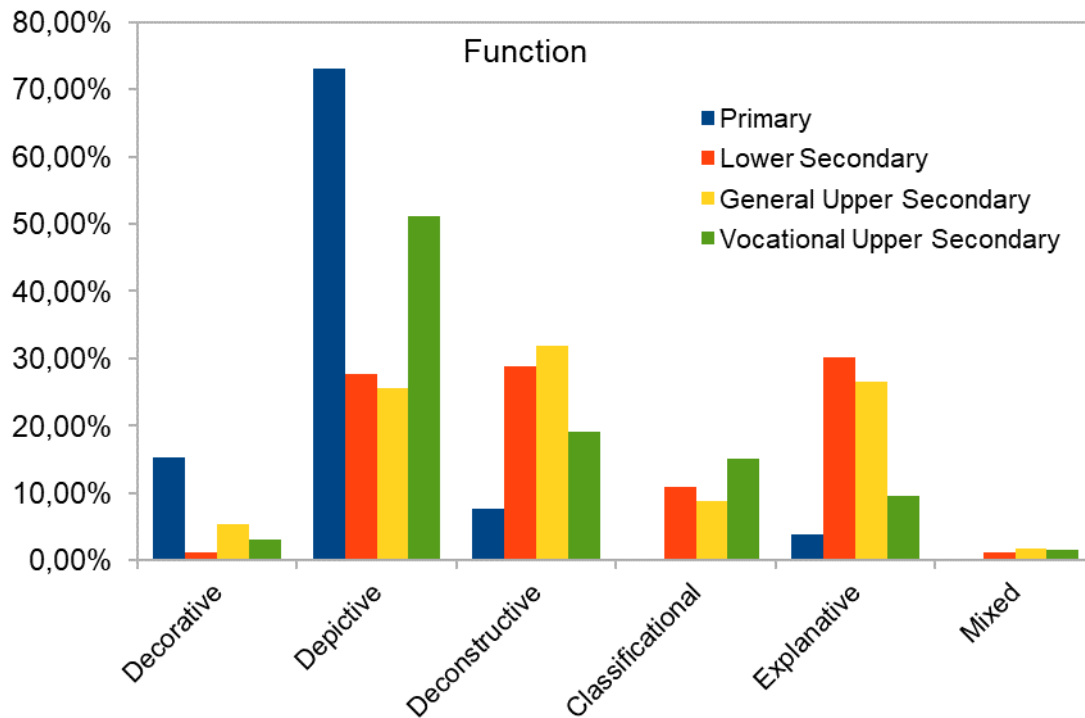
Figure 2: Distribution of visual representations of the cell among the four examined educational levels according to their function

Based on the level of the representation, strong evidence is provided for a statistically significant different distribution between the four educational levels (Pearson Chi-Square=47,383, df=15, p<0.001). As shown in Figure 3, the microscopic representations of the cell are the ones most frequently encountered in the textbooks of primary and vocational upper secondary schools (with similar high percentages equal to 76,9% and 69,6% respectively).
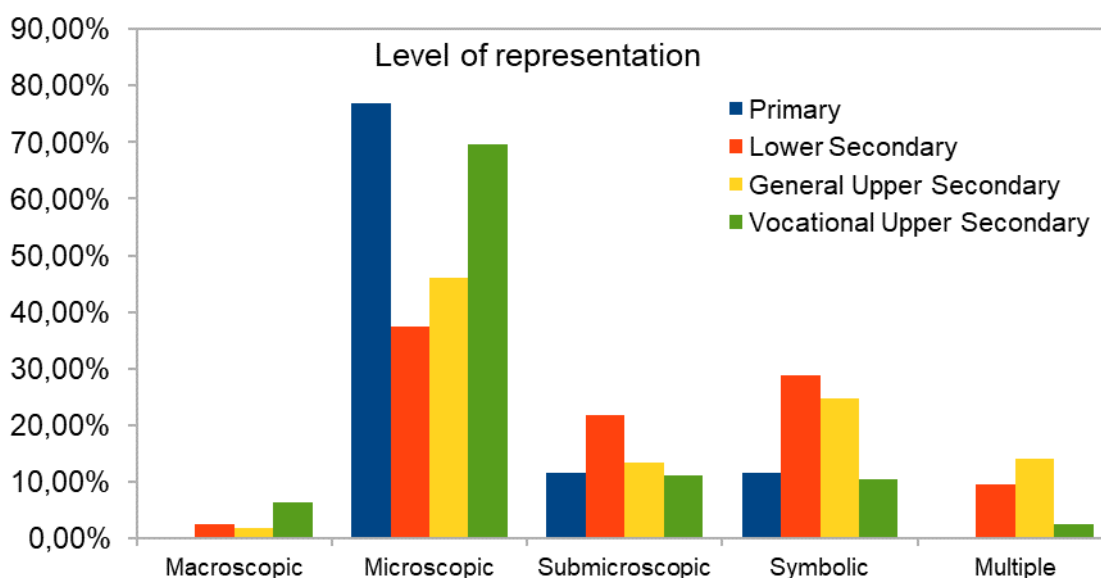

Figure 3: Distribution of visual representations of the cell among the four examined educational levels according to their level of representation

The same trend, however, with lower intensity, is observed also for the textbooks of lower secondary and general upper secondary schools (percentages 37,3 % and 46,0% respectively). Interestingly, the

symbolic representations are the second most frequently appearing in the textbooks of both lower secondary and general upper secondary schools, with similar percentages of 28,9% and 24,8% which are more than double than the ones of the other school types. Finally, two additional interesting points of differentiation is the relatively elevated frequency of the submicroscopic cell representations in lower secondary school (21,7%) and the almost exclusive appearance of multiple cell representations solely in lower secondary and general upper secondary school.

3. Conclusions
The present study provided detailed information with regard to the characteristics of the visual representations of the cell that are present in a total of 14 biology textbooks of the four distinct school types in the Greek educational system. A total of 347 identified cell representations were uniquely assigned to categories based on a three-dimensional classificational scheme which involved the following three criteria: degree of abstractness, function, level of representation.

Strong evidence was provided for statistically significant differences between the types of cell representations encountered in the four educational levels. More specifically, in all three dimensions used for the classification analysis, evidence is provided for the existence of two distinct sets of educational levels. One set refers to the cell visual representations that are contained in the textbooks of primary and vocational upper secondary school and the other set is composed of the remaining two educational levels ie lower secondary and general upper secondary school.

Future work will involve more in depth analysis of the characteristics of the identified cell representations in order to explore possible correlations between the different classification dimensions, as well as the investigation of the role of the type of the representation in students' understanding of the cell concept.

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