Students' Conceptions of Biological Images as Representational Devices

Concepciones de los Estudiantes sobre Imágenes de Biología como Mecanismos Representacionales

Concepções dos Estudantes sobre Imagens de Biologia como Mecanismos Representacionais

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Abstract

The study analyzes students' conceptions of the representational nature attributed to images in biology. The conceptions regarding the relationship between representation and referent can be categorized into realism and constructivism. 171 students aged 12, 14, and 16 participated in the study. Some had had specific instruction in biology and some had not. Several instruments, such as Likert scale questionnaires, and multiple choice and open-ended questions were used to measure the conceptions. Students show realistic conception about the nature of a cell microphotography. The primacy of perceptive aspects in visual representations may explain these results, the difficulties students have in learning them, and the need of their explicit instruction.

Keywords: students' conceptions, learning, visual representation, representational nature of images, biology, learning difficulties.

Resumen

Este estudio tuvo como objetivo analizar las concepciones de los estudiantes sobre la naturaleza representacional de las imágenes en biología. Las concepciones sobre la relación entre la representación y el referente pueden categorizarse como realista o constructivista. Para tal fin, 171 estudiantes de 12 a 16 años, con y sin instrucción específica en biología, respondieron cuestionarios de escala Likert, con preguntas abiertas y de opción múltiple. En general, los estudiantes mostraron una concepción realista sobre la imagen de una célula. La primacía de los aspectos perceptivos de las imágenes puede explicar estos resultados, así como las dificultades que tienen los estudiantes en su aprendizaje y la necesidad de su instrucción explícita.

Palabras clave: concepciones de estudiantes, aprendizaje, representaciones visuales, naturaleza representacional de las imágenes, biología, dificultades en el aprendizaje.

Resumo

Este estudo teve como objetivo analisar as concepções dos estudantes sobre a natureza representacional das imagens em biologia. As concepções sobre a relação entre a representação e o referente podem categorizar-se como realistas ou construtivas. Para isso, 171 estudantes de 12 a 16 anos, com e sem instrução específica em biologia, responderam a questionários de escala Likert, com perguntas abertas e de múltipla escolha. Em geral, os estudantes mostraram uma concepção realista sobre a imagem de uma célula. A primazia dos aspectos perceptivos das imagens pode explicar esses resultados, assim como as dificuldades que os estudantes têm em sua aprendizagem e na necessidade de sua instrução explícita.

Palavras-chave: concepções de estudantes, aprendizagem, representações visuais, natureza representacional das imagens, biologia, dificuldades na aprendizagem.

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SCIENTIFIC RESEARCH ARTICLE
RECEIVED: 1 MARCH 2012 - ACCEPTED: 18 AUGUST 2012

* Este estudio forma parte del proyecto de investigación EDU2010-21995-C02-01, financiado por el Ministerio de Ciencia e Innovación del gobierno español y dirigido por J. I. Pozo.

SCIENCE CONVEYS its knowledge not only through words but also through images (Lemke, 1990; Lynch, & Woolgar, 1990; Mathewson, 1999). This type of representation systems holds an increasingly important place not only in science but in current society (Andersen, Scheuer, Pérez-Echeverría, & Teubal, 2009). Examples of these systems are diagrams, illustrations, photographs, maps, graphs, models, and tables. All of these are characterised by a visual and a spatial nature, since they are marks carried out in space. These visual-spatial systems[1] are forms of representing, handling, communicating, learning, solving problems, and reconsidering scientific knowledge.

One way to discriminate among images is to consider the degree of similarity or analogy between the image and the represented object (Martí, 2003; Pérez-Echeverría, Postigo, López-Manjón, & Marín, 2009; Shah, Freedman, & Veriki, 2005). Thus, we can establish an analogic-arbitrary continuum in which to situate the different types of images. At one end of the continuum would be the group of "iconic" or "figurative" representations, such as photographs, illustrations and drawings, which reproduce the spatial characteristics of the referent with a high similarity. At the other end of the continuum would be the group of abstract representations such as graphs, tables, maps, and diagrams, which, due to their abstract nature, show less fidelity between the image and the referent and a more selective or schematic correspondence between both elements. Nevertheless, all of them share the feature of enabling an integrated and simple representation of large amounts of information and knowledge that are interrelated in a complex manner (Barquero, Schnotz, & Reuter, 2000) or information difficult to report by words (Roth, Pozzer-Ardenghi, & Han, 2005).

1 Although our use of terms such as image, visual, graphical or figurative representations is interchangeable, the term visual-spatial representation seems to us the most appropriate because, as we have just pointed out, it covers an essential part of these representations such as their spatial nature.

Our argument is that if visual-spatial systems are fundamental in science, they should be taken into account for the successful learning of science (Mathewson, 1999). Of all the different aspects of visual-spatial systems, we are interested in their representational nature, that is, the relationship established between the representational setting (an image or visual-spatial representation) and what is represented (its referent). Various studies reveal that, in spite of the difficulty of the dual nature of these systems (they are simultaneously objects and symbolic representations), the capability to make a distinction between the representation and that represented occurs very early on (DeLoache, Pierroutsakos, Uttal, Rosengren, & Gottlieb, 1998; Perner, 1991). However, the difficulty is not simply to discriminate between both elements but to think about them, that is, to understand and to be aware of the complex relationship between the two elements, which is the aim of this study. From our perspective, this aspect has an influence on teaching and learning about scientific images and, therefore, on the acquisition of scientific knowledge.

There are two ways of conceiving the relationship between the representation and the referent based on the epistemological relationship between knowledge and reality (Pozo & Gómez, 1998; Vosniadou, 1994).

A so-called realistic conception is based on the principle of correspondence according to which our representations would be a copy of reality; learning would be making copies of the object; and teaching would be clearly showing the object (Pozo, Scheuer, Pérez-Echeverría, Mateos, Martín, & De la Cruz 2006). In the case of visual-spatial representations or images, the iconic nature and, therefore, the relationship of similarity between representation and that represented would account for the attribution of a realistic nature compared to other systems of representation such as writing or numerical annotation whose relationship is arbitrary. This fact makes visual representation especially "transparent" (Lowe, 1993, p. 24) and, therefore, specific teaching or instruction to be able to interpret and understand it is unnecessary (Reid, 1990). It is assumed that processes of translation or extraction of meaning in the image are not necessary, that is, their meaning is obtained automatically. This conception also seems aimed at the treatment given to visual representations in science textbooks at different educational levels (Jiménez & Perales, 2001; López-Manjón & Postigo, 2008; Postigo & López-Manjón 2012; Stylianidou & Ogborn, 2002), where there is little help to interpret the textbook images.

On the other hand, if knowledge is a copy or a "reflection" of how things are, knowledge can only be "true" or "false" because there is just one reality. Translating this idea into visual representations, it is only possible to assume the existence of a single true image of an object, unless the existence of different images is accepted, because they refer to different objects (e.g., different images of the cell would be possible because there are different kinds of cells). This could be called the "naïve realistic" conception. However, this conception seems to develop through age and instruction toward the so called "interpretative realism", which implies a more complex way of understanding the relationship between knowledge and reality (Pozo et al., 2006). Although that knowledge reflects reality and the learning goal is to copy reality, it is almost impossible to achieve this with exactitude. According to the above conception, the reason why it is impossible to achieve an exact copy of reality has to do with factors related to the student and to the task. The need for students to carry out complex cognitive processing (attention, memory, motivation, etc.), together with certain characteristics of students (intelligence, cognitive development, previous knowledge), and the need of specific practical conditions to learn make it very difficult to attain "real or true knowledge" (Pozo & Gómez, 1998). The interpretative realistic conception accepts the existence of more than one type of knowledge, but accepts only one as true. Translating this idea into visual representations, even when the presence of various images to represent an object is accepted, there will always be one image which "really" captures the object, and so it would be considered the true one. The other images will not be true because of criteria related to technical or editing factors which hinder their correct perception.

The second way of understanding the relationship between representation and the object represented would be the so-called constructivist conception which assumes that the representation (the image in this case) is a construction in the sense that it is one of the possible perspectives from which the object can be represented. Contrary to the realistic conception, learning visual representations would not be a process of making copies of reality but rather a process of re-construction aimed at interpreting and producing such representations (Martí, 2003). In addition, there would not be a sole true representation because there may be many different representations referred to the same reality and with the same true status (Pozzer-Ardenghi & Roth, 2003). An image is a particular way of representing reality and may be interpreted differently according to several factors: the internal characteristics inherent to the visual-spatial representational system, the background knowledge of the observer, and the aims for which this representation is used. Regarding the first factor, for example, visual representations in biology and especially the representations of anatomical structures have some specific characteristics: (a) they are representations which often have to reflect three dimensions; (b) they are structures which inevitably contain other internal structures and, (c) in order to represent internal anatomic structures, it is necessary to use specific structural sections (e.g., sagittal, ventral, etc.). According to Constable, Campbell, and Brown (1988), students have problems interpreting visual representations in biology because they are unaware of the conventions used with different types of sections. Therefore, students should have not only a sound command of the grammar of systems (their syntaxes) and their meaning (their semantics) but also of their strategic use with various purposes or aims (e.g., with the aim of communicating based on who they are aimed at). We assume that learning and teaching visual representations is a highly complex process as shown by research about students' difficulties (e.g. Díaz & Jiménez, 1996; Pintó & Ametller, 2002).

From our perspective, one of the greatest difficulties in learning science is making students see that images are representations of objects and concepts and not objects in themselves. This means moving away from a realistic/interpretative realistic conception toward a constructivist conception (Gómez & Pozo, 2004) of visual representations in science.

Research has been carried out regarding epistemological conceptions or beliefs about knowledge in general (e.g., Hofer & Pintrich, 2002; Schommer, 1990; Schraw, Bendixen, & Dunkle, 2002), from a quantitative and psychometric approach, taking an analytical and structural view of the components and dimensions of these beliefs. Also, research on science learning has focused on conceptions of scientific knowledge due to their influence in the learning and teaching of science (Leach, Millar, Ryder, & Sere, 2000; Thoermer & Sodian, 2002). However, we have not found any studies that analyze these conceptions in relation to scientific images. In this study, our approach differs from the quantitative and psychometric approach and coincides with the science learning approach but focusing on the images in science learning. Thus, the aim of this exploratory study is to analyze conceptions of representational nature (from realism to constructivism via interpretative realism) which students of different ages (12, 14 and 16 years old) and different specific biology instruction attribute to one kind of image: a cell photomicrograph. We expect to find that students show realistic conceptions related to visual representations. From the approach proposed here, the attribution of a realistic nature to images by students would be accounted for by the important role that perception plays in cognition as the hypothesis of embodied cognition maintains (Gibbs, 2006; Pozo & Gómez, 2005). This realistic nature would be one of the restrictions on the basis of which we would build our intuitive representations of the world as verified in other domains of knowledge (e.g. Gómez & Pozo, 2004; Vosniadou, 1994).

Specifically, we are interested in answering the following questions:

First of all, what conceptions do students have about the representational nature of an image? Are they the same as the conceptions about scientific knowledge? We think that a complex topic like this, mainly due to its implicit nature, should be approached using a variety of instruments. Thus, we gave students a questionnaire, adapted from Pecharromán and Pozo (2006), in which they had to choose, in a Likert scale, among different conceptions of a biological image. We also compared them with the results of applying the same questionnaire (Pecharromán & Pozo, 2006) about scientific knowledge, to see whether the conceptions were the same or not. Finally, we analyzed the conceptions using two other tasks: multiple choice and open-ended questions.

Secondly, do these conceptions about the nature of an image vary according to age/educational level, on the one hand, and depending on the level of specific biological instruction, on the other? We wanted to transversally research the development of these conceptions between the ages of 12 and 16. Considering the research in other contexts (Kuhn, Cheney, & Weinstock, 2000; Mason, 2002; Pérez-Echeverría, Mateos, Pozo, & Scheuer, 2001; Pozo & Gómez, 1998) we wanted to know whether, in their educational process (inextricably linked to age), students advance toward more complex image conceptions such as the constructivist one. Thus, the realistic conception would be found more frequently among groups of younger students, and interpretative realistic conceptions in older students as an intermediate stage in the transition from realistic to constructivist conceptions. We also expected to find more constructivist conceptions in students with specific instruction in biology, compared to students of the same age and with no specific instruction in biology. However, taking into account the results of the previous studies, we cannot be sure that these differences are remarkable. Finally, as an exploratory question and as a consequence of the supposed realistic attribution, we expected to find certain conceptions of learning and teaching about visual representations. Specifically, we wanted to see whether image processing and interpretation can be attributed to a certain innate capacity (intelligence or visual-spatial capability) (Hofer & Pintrich, 2002; Schommer, 1990) or not. We also wanted to know whether students think that visual representations do not need to be taught (Lowe, 2007; Reid, 1990). The idea was to compare these results to those obtained by applying the scientific knowledge questionnaire also used in the Pecharromán and Pozo (2006) study.

Method

Participants

In order to analyze the development of students' conceptions at different ages and the effect of specific instruction in biology, we selected students from several educational levels in secondary and high school[2]. We chose secondary education because that is when students begin to receive instruction in biology as an independent subject, instead of the global instruction given in primary education. In the case of high school, besides the comparison with the secondary level, we were interested in the effect of specialized instruction in biology on two groups (those with and without specialized instruction in biology). We performed a cross-sectional study from the beginning of secondary education to high school also exploring an intermediate level in secondary school. We chose the groups taking into account a difference of two years of age between them.

The total sample was made up of 171 participants divided into four groups. The students were all middle-class and attended the same public secondary and high school in Madrid (Spain). We selected the students from the already formed complete regular class groups. The characteristics of the four groups were the following:

1. 51 students from the first year of compulsory secondary education (1ºCSE) (comprised of 28 male and 23 female students. Mean age: 12.76 years) (in the Observe this Image task, three participants who did not complete the task were eliminated; there were 48 students for this task).

2. 49 students from the third year of compulsory secondary education (3ºCSE) (comprised of 18 males and 31 females. Mean age: 14.48 years) (in the Observe this Image task, two participants who did not complete the task were eliminated; there were 47 students for this task).

3. 32 students from the first year of A level (social sciences) (1ºA-SS): (comprised of 10 males and 22 females. Mean age: 16.72 years). This group had had specific instruction in social science subjects.

4. 39 students from the first year of A level (natural sciences) (1ºA-NS): (comprised of 27 males and 12 females. Mean age: 16.61 years). This research was performed at the end of the academic year for which reason the group had had specific instruction in biology.

Instruments

To analyze the characteristics of students' conceptions, we used four instruments:

1. The Natural Sciences Questionnaire was used with the aim of analyzing the characteristics

2 The Spanish educational system includes four years of mandatory secondary education for students between the ages of 12 and 16. There are two years of high school (students between the ages of 17 and 18), in which students may choose among different modalities with specific instruction in social sciences and natural sciences, among others before going on to the university.

of students' conceptions of scientific knowledge in the natural sciences, designed by Pecharromán and Pozo (2006), and to compare them to the conceptions about the image. This questionnaire is an adaptation of the instrument designed for the classical research group of epistemological beliefs (Schommer, 1990; Schraw et al., 2002). By means of expert validation (psychology and philosophy experts), Pecharromán and Pozo (2006) adapted this questionnaire to the natural science domain regarding conceptions of the nature of knowledge and conceptions of the acquisition of knowledge. The questionnaire is comprised of 22 items in six scales (objectivism, relativism, constructivism, immediate knowledge, restricted knowledge, and shared knowledge) with a Likert-type scale response format; *agree-disagree* on a 6-point scale. Although we applied the original questionnaire, we were only interested in analyzing the items of some of the scales (see Appendix A) grouped together in the following way:

- Realistic scale comprised of items 1, 4, 18, and 22 (from the original objectivism and immediate knowledge scales). For example, "A discovery or proven scientific law is and always will be true".
- Constructivist scale comprised of items 3, 6, and 16 (from the original constructivism scale). For example, "The effort of scientists may attain an increasingly more approximate knowledge of what occurs in nature but they will never ever be sure of their theories".
- Innate-Learned scale comprised of items 7, 15, and 17 (from the original restricted knowledge and shared knowledge scales). For example, "For the most part, scientific laws arise from or are discovered in our inner selves; we don't need to be taught these laws".

We obtained the mean score in each scale for each group of participants.

2. The Image Questionnaire was based on the above questionnaire (Pecharromán & Pozo, 2006). The aim was to analyze conceptions of a cell image, focusing on relationships between the representation and its referent (realistic, constructivist) and certain ideas regarding how images are learned (innate or learned ability). We validated this adaptation by a group of experts (3 university teachers in epistemology and 3 in science learning) who assessed the adequacy of each item to the related conception. Subsequently, we tested the task in several pilot studies with 173 participants (A level students and university students with different levels of instruction in biology and a group of secondary biology teachers) (see López-Manjón & Postigo, 2009). As a result of these pilot studies, we defined a 17-item questionnaire with a 6-point Likert-type scale response format to measure the degree of agreement with the different statements (see Appendix A). The questionnaire is comprised of three scales which reflect two kinds of conceptions (realistic and constructivist conceptions), and some ideas on the nature of capabilities (innate or learned) necessary to interpret images. All of the questionnaire items refer to the image of a cell presented on the first page of the questionnaire.

- The Realistic scale is comprised of seven items: 3, 5, 7, 10, 12, 14, and 16. For example, "Good images of a cell are those which reliably and exactly reflect what a cell is".
- The Constructivist scale is comprised of seven items: 2, 4, 6, 8, 11, 13, and 15. For example, "There are no correct and incorrect images of a cell as this depends on several factors, for example, the purpose for which we wish to use it, whom it is aimed at, etc."
- The Innate-Learned scale is comprised of three items: 1, 9, and 17 (scores near 6 points on the Likert scale mean an innate conception). For example, "It is sufficient to look at a cell's image to understand it and it is not necessary for us to be taught to look at it".

We obtained the mean score in each scale for each group of participants.

3. The Agreement Task was designed to analyze the representational nature attributed to a cell's image. The first sheet of the task presented the cell's image and a situation in which three supposed students made certain comments corresponding to the three conceptions of the relationship between scientific images as representation and their referent (realistic, interpretative realistic and constructivist conceptions): Student 1: "This image shows what a cell is really like. This is an image in which all the important aspects can be identified. This is the only way to show what a cell is really like." (realistic conception). Student 2: "This image shows one of the possible ways of presenting what a cell is really like. However, among all those that can be made is quite a good and clear image which shows us what it is really like" (interpretative realistic conception). Student 3: "This image shows a specific vision of a cell from a certain point of view. It does not present us with all the aspects of the cell, but only with those they want to highlight for some reason." (constructivist conception). The task required participants to select the student statement expressing the position most closely aligned with their own opinions, and to justify their choice.

In the Agreement Task, for each group of participants we obtained the percentage of choice for each one of the conceptions: realism (1), interpretative realism (2) and constructivism (3). In addition, the participants had to justify the choice. The criteria to categorise justifications were the following:

0 = No justification: this category includes participants who did not respond, those who repeated the opinion of the student they had chosen, and those who gave tautological justifications in which no type of information or new idea was provided.

1 = Realistic conception: includes those justifications which emphasised the idea that the image shows reality, from which it is evident that it is real because it is a photograph. In case of accepting this, there are different ways of presenting a cell because there are different types of cells and, therefore, different referents.

2 = Interpretative realistic conception: justifications in accordance with the idea that there are various ways of presenting a cell and that these refer to stressing some aspects and not others, but without mentioning the reasons for which they are stressed. We also resorted to visual clarity or resolution to explain the presence of different ways of presenting them.

3 = Constructivist conception: justifications which consider the presence of different viewpoints based on criteria such as the importance of aspects emphasized, the nature of the object (three-dimensional vs. two-dimensional; external vs. internal), and the intention of the observer. All these criteria are used when considering the presence of different representations for a same object.

The justifications of participants were classified entirely by the two authors, working independently and on the basis of the previous four categories. A high level of inter-judge agreement was attained (Kappa coefficient=0.864; $p<.001$). The discrepant cases were resolved by consensus.

4. Observe this Image. This task involved the presentation of the image of a cell, followed by five open questions on the relationship between representation and its referent. The purpose of Question 1 ("What appears in the image?") was to analyze whether participants mentioned only the referent or the idea of representation. For Question 2 they had to state how they believed the image was obtained. Question 3 referred to whether they believe it is possible to produce different versions of the same image. Questions 4 and 5 asked them to analyze the characteristics of the production of images by two biologists faced with the same object (Question 4) and state which one shows the object better (Question 5). These two questions refer to the possibility of assuming the presence of various representations of the same object and in this case the criterion to decide which representation is the best or correct one (see Appendix A).

Table 1
Criteria for Analysis of Conceptions of the Relationship between the Representation and its Referent

Conception	Realistic	Interpretative realistic	Constructivist
Question 1 *What is it?*	The referent	--	A type of representation
Question 2 *How was it obtained?*	Technical mechanism for obtaining the image	--	Model or theory which is the product of a prior study.
Question 3 *Other versions?*	No other versions can be made. Yes, because there are different kinds of referents.	Yes, because of aspects such as their resolution, colour, clarity, brightness, larger or smaller size, or a fuller, more detailed image …	Yes, highlighting alternative ways of representing the image.
Question 4 *Productions of 2 biologists*	Would be the same and the same as the referent (because they saw the same object.)	They will be similar but with differences because the biologists have focused on certain points or draw differently.	Different because of diverse points of view, different knowledge and/ or understanding of the subject. They would be similar because the biologists have the same knowledge.
Question 5 *Which is the best?*	Exact similarity with the referent or original (book, expert…)	More or less the same, the one that is more complete has more details…	Knowledge of the phenomenon. They include correct aspects which were not there initially.

In the task Observe this Image, responses were classified according to the criteria collated in Table 1 and with the three conceptions of the relationship between scientific images as representation and their referent. We assigned a score of 0 when they had not interpreted the question correctly, they did not answer, or they did not know.

We assigned the score of 1 for the realistic conception, 2 for the interpretative realistic conception, and 3 for the constructivist conception. We pointed out that a low number of participants (4.2% of the sample) gave responses which could be classified simultaneously in more than one conception, giving them a mixed score for the different conceptions they showed (e.g., realistic and constructivist conception “1+3”). These cases were categorized into a mixed conception category. We obtained the percentage of each one of the conceptions in each group for each of the questions. The categorisation of responses given by participants was classified entirely by both authors, working independently on the basis of the previous five categories. The results of inter-judge agreement (Kappa coefficient) attained satisfactory values (varying between 0.664 and 0.834). The discrepant cases were resolved by consensus.

The Agreement Task, the Observe this Image, and the Image Questionnaire were presented together with a cell photomicrograph (n.d.). The image represents a eukaryotic colour-dyed cell in which the plasma membrane, nucleus and nucleolus are differentiated; the cytoplasm organs are not at all differentiated (size 5.5x8cm) (see Appendix B). The reason for including an image in all tasks and questionnaire was the need to ensure that all participants were thinking about the same image in their answers. This type of image was selected because of its representativeness in the biological domain and also because we expect to find more realistic conceptions in this kind of visual-spatial representation due to their iconic nature (Pozzer-Ardenghi & Roth, 2003), compared to structure or process diagrams (Lowe, 1993, 2007).

Procedure

First, we applied the task Observe this Image followed by the Agreement Task and finally the two questionnaires (Image Questionnaire and Natural Sciences Questionnaire). To counterbalance the order effects of the last two questionnaires, we first administered the Image Questionnaire and secondly the Natural Sciences Questionnaire to one half of each group and then in reverse order to the other half of the participants. Tasks were administered at the same time to the entire group in their usual rooms. The time available to perform the tasks was unlimited. The two groups of secondary students (1ºCSE and 3ºCSE) took a mean time of one hour to complete all the tasks and in the two A level groups (1ºA-SS and 1ºA-NS), the mean time was forty minutes.

Results

In Table 2, we can find a summary of the statistical test carried out, the instruments used, and the objective of each analysis.

We report the results organised according to the three questions of the study (see introduction section).

1. What conceptions do students have about the representational nature of an image? Are they the same as the conceptions about scientific knowledge?

The analysis of variance (ANOVA 4x2x3) revealed a statistically significant effect for the variables Group $F(3, 5.791)=5.749$, $p=.001$, Questionnaire $F(1, 58.6)=115{,}812$, $p<.001$, and Scale $F(2, 78.254)=106.849$, $p<.001$, and the interactions Questionnaire by Scale $F(2, 14.319)=28.49$, $p<.001$, and the three-fold interaction of the three variables Questionnaire by Scale by Group $F(6, 1.137)=2.26$, $p=.037$. Given the result of the threefold interaction, we proceeded to first break down the interaction of the variables Group and Scale, that is, we calculated the interaction separately for the two types of Questionnaire (with two ANOVAS 4x3) and secondly the interaction of the variables Group and Questionnaire, that is, we calculated the interaction separately for the three kinds of scale (with three ANOVAS 4x2). Therefore, the results of the questionnaires come from these lasts analyses.

In connection with the above question, we present statistically significant results of the questionnaire analysis followed by analysis scales.

In the Image Questionnaire, the behaviour of the four groups in the three questionnaire scales (ANOVA 4x3) reveals an effect of the variable Scale $F(2, 36.605)=80.896$, $p<.001$. According to Figure 1, there is a higher score in the Realistic scale. Comparing the three scales by means of multiple comparisons, we see that the score on the Realistic scale is significantly higher than that of the other two scales, and that the score on the Constructivist scale significantly exceeds the Innate-Learned scale ($p<.05$).

Table 2
Summary of the Statistical Analyses

Instrument	Objective of analysis	Statistical analysis
Image Questionnaire Natural Sciences Questionnaire	To compare the performance of the four groups on the three scales of the two questionnaires.	(ANOVA 4x2x3) (two ANOVA 4x3) (three ANOVA 4x2) Tukey test with Bonferroni correction
Agreement Task	The distribution of conceptions across the four groups both in selection and justification parts of the task.	Chi-square test with adjusted standard residual
	The relationship between conception chosen in the selection and in the justification parts of the task.	Chi-squared test with adjusted standard residual
Observe this Image Task	The distribution of conceptions in the five questions throughout the four groups.	Chi-square test with adjusted standard residual

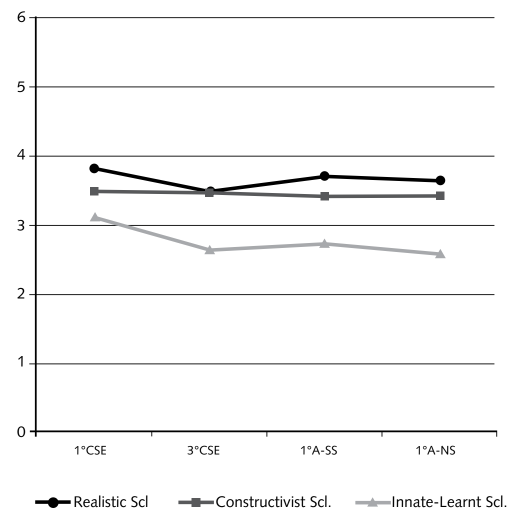

Figure 1. Mean scores (degree of agreement) of the different groups on the three Image Questionnaire scales.

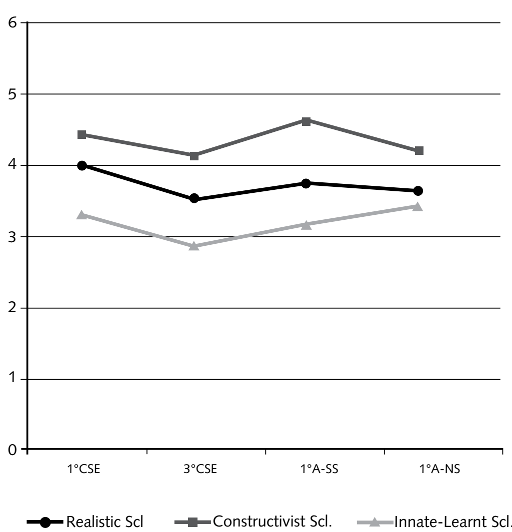

Figure 2. Mean scores (degree of agreement) of the different groups on the three scales of the Natural Science Questionnaire.

In the case of the Natural Sciences Questionnaire, the behaviour of the four groups on the three questionnaire scales (ANOVA 4x3) also reveals an effect of the variable Scale $F(2, 56.427)=72.324$, $p<.001$. As shown in Figure 2, we obtained a higher score on the Constructivist scale, significantly higher than the other two scales, while the Realistic scale significantly exceeds the Innate-Learned scale ($p<.05$).

In the Constructivist scale, the behaviour of the four groups on the two questionnaires (ANOVA 4x2) reveals an effect of the variable Questionnaire $F(1, 70.246)=157.674$, $p<.001$. Participants attained a higher score on the Natural Sciences Questionnaire ($p<.05$).

2. Do these conceptions about the nature of an image vary according to age/education level on one hand and to different levels of specific biological instruction, on the other? Although we presented the statistical analysis taking into account the variable *group* with four levels, we considered the influence of age/education comparing the results of 1°CSE, 3°CSE, and either 1°A-NS or 1°A-SS groups. On the other hand, we considered the influence of different levels of specific biological instruction, comparing the performance between 1°A-NS and 1°A-SS groups.

In the Realistic scale, the behaviour of the four groups in the two questionnaires (ANOVA 4x2) also revealed an effect of the variable Group $F(3, 2.598)=3.772$, $p=.012$. The behaviour on this scale is quite similar among the four groups. The Tukey test only revealed that on this scale the 1ºCSE group significantly exceeds the 3ºCSE group ($p<.05$).

In the Agreement Task, the analyses of the selections revealed differences between the groups (χ^2 (6, N=171)=18, 342, $p=.005$), and we were able to conclude that the group variable and type of conception are related. As Table 3 shows, the choice of a realistic conception was significantly more frequent in the 1ºCSE group and the least frequent in the 3ºCSE group. The interpretative realistic conception was selected significantly more by the 3ºCSE group, while the constructivist conception was selected significantly more frequently by the 1ºA-NS group.

In the Agreement Task, the analyses of the justifications revealed differences among the groups ($\chi^2(9, N=171)=27, 224, p=.001$) so we were able to conclude that the group variable and type of justification are related. As can be seen in Table 4, the categories *no justification* and *realistic justification* were the justifications of the initial selection shown by the 1ºCSE group in significantly greater proportions. This group also revealed fewer *interpretative realistic justifications*. Conversely, the 3ºCSE group showed a much higher proportion of *interpretative realistic justification*, while the 1ºA-SS and 1ºA-NS groups did not show any significant trend regarding their type of justifications.

With respect to the relationship between selection and justification, there were differences among the choices ($\chi 2(6, N=171)=80{,}786$, $p<.001$) for the type of subsequent justification of the characteristics of the cell's image. In other words, we concluded that the variable type of selection and type of justification are related. The type of justification given for the three kinds of initial selection of the characteristics of the cell's image for all participants showed the following trend: realistic selections show a realistic justification; interpretative realistic selections show an interpretative realistic justification; and constructivist selections show a constructivist justification.

Table 3
Distributions (as Percentages) of the Type of Conceptions in the Selections Conditioned to the Group in the Agreement Task

Group		Realism	Interpretative realism	Constructivism	Total
1ºCSE	%	33.3*	31.4	35.3	100%
3ºCSE	%	6.1**	53.1*	40.8	100%
1ºA-SS	%	18.8	37.5	43.8	100%
1ºA-NS	%	15.4	25.6	59*	100%
Total % expected		18.7	37.4	43.9	100%

Note: * Significant adjusted residuals (values>2) are highlighted in dark grey.

** Significant adjusted residuals (values<2) are highlighted in light grey.

Table 4
Distributions (as Percentages) of the Conceptions Used in the Justifications Conditioned to the Group in the Agreement Task

Group		Don't know/ don't answer	Realism	Interpretative realism	Constructivism	Total
1ºCSE	%	49*	25.5*	9.8**	15.7	100%
3ºCSE	%	26.5	14.3	46.9*	12.2	100%
1ºA-SS	%	18.8	15.6	37.5	28.1	100%
1ºA-NS	%	28.2	7.7	38.5	25.6	100%
Total % expected		32.2	16.4	32.2	19.3	100%

* Significant adjusted residuals (values>2) are highlighted in dark grey.

** Significant adjusted residuals (values<2) are highlighted in light grey.

However, we should point out that when we analyze data by groups, we can obtain further information on the relationship between selection and justification. We consider that a student is "consistent" when he/she has the same conception in the selection and justification tasks, and "non-consistent" when he/she switches the conception in the justification. As we can see, with the exception of the 1ºA-SS group, there was a low percentage of consistent students (see Table 5). Although some participants did not show arguments in accordance with the conception of their initial selection in their justification, these justifications are systematically of a lower level than the conception considered in the selection. For example, students who chose a constructivist conception may have provided an interpretative or realistic justification, or those who chose an interpretative conception gave a realistic justification.

One case worth highlighting is the direction of justifications from non-consistent participants who started out from a constructivist selection. The explanation for non-consistent participants from 1ºCSE was the fact that half this group (52%) did not know or did not justify their choice. In the case of non-consistent students from 3ºCSE, although a high percentage did not know or did not justify their choice (35%) the majority justified it in an interpretative realistic manner (45%). The most surprising case was that of non-consistent students from 1ºA-NS because, despite being the group which obtained a higher proportion of constructivist choices compared to others, half the group justified their choice in an interpretative realistic manner (52.17%).

In the Observe this Image task, there were differences among the groups exclusively in Question 3 ("Other versions?") and Question 5 ("Which is the best?"). Thus, the variable group and type of conception in these two questions are related. In Question 3, there were differences among groups ($\chi^2(18, N=166)=29, 202, p=.046$) regarding the conceptions of the possible existence of other versions of the cell's image. In the 1ºCSE group, we observed a higher number of cases in the realistic conception, while in the 3ºCSE group we observed that this realistic conception is significantly less frequent. The 1ºA-SS and 1ºA-NS groups did not reveal any significant trend regarding their type of conceptions. In Question 5, there were differences among the groups ($\chi^2(15, N=166)=29, 117, p=.016$) regarding the conceptions of the way in which they know which of the two biologists has best shown the cell. We observed a statistically significant higher number of cases in the category *does not know/does not answer* in the 1ºCSE group, that is, this group had more difficulties knowing which of the two biologists had best portrayed the cell. The 1ºA-SS group showed a realistic conception, while the 1ºA-NS group featured a constructivist conception and a mixed realistic and constructivist conception.

Table 5
Percentage of Students who are Consistent, Not Consistent, or Don´t Know/Don´t Answer with Respect to their Justification of the Conception Shown in the Selection Task

Group	Consistent	No consistent	Don't know/don't answer
1º CSE	41.1%	9.8 %	49%
3º CSE	40%	32.65 %	26.53%
1ºA-SS	65%	15.60 %	18.75%
1ºA-NS	33.33 %	38.48%	28.20%

3. What kind of conceptions do students have regarding learning and teaching about images, compared to scientific knowledge?

In the Innate-Learned scale, the behaviour of the four groups on the two questionnaires (ANOVA 4x2), showed an effect of the variable Group $F(3, 3.515)=3.438$, $p=.018$. The Tukey test showed that the 1ºCSE group had more innate conceptions than the 3ºCSE group ($p<.05$).

The analysis also revealed an effect of the variable Questionnaire $F(1, 16.282)=23.983$, ($p<.001$). The Natural Sciences Questionnaire led to a much higher score (more innate) than the Image Questionnaire ($p<.05$). Finally, this analysis also revealed an effect of the interaction of the variables Group by Questionnaire $F(3, 1.890)=2.784$, $p=.043$. There were significant differences among the groups only in the Image Questionnaire. Specifically on this scale, the 1ºCSE group significantly exceeded and, consequently, had more innate conceptions (scores near 6 point) than the 3ºCSE and 1ºA-NS groups.

Discussion

This study was an initial attempt to examine the representational nature that students attributed to biological images, considering the lack of studies on this subject. Firstly, we expected students to attribute a realistic nature to images such as a cell photomicrograph, compared to the conceptions attributed to scientific knowledge of natural science. This initial idea was confirmed by the following results: (a) In the Image Questionnaire, participants attributed a higher score to the realistic scale and in the Natural Sciences Questionnaire they attributed a higher score to the constructivist scale; (b) in the Constructivist scale, participants obtained a higher score on the Natural Sciences Questionnaire than on the Image Questionnaire. However, in the Realistic scale we did not find scores on the Image Questionnaire to be higher than on the Natural Sciences Questionnaire, which would support our initial idea.

Other data which would also support the above idea of realism for images are some questions from the Observe this Image task in which we found no intergroup differences. Both in the question on obtaining the image (Question 2) and the question regarding what the images of the two biologists who are looking at the same object would be like (Question 4), the realistic conception was the one more frequently used by all the groups. However, we wish to mention some aspects of Question 1 ("What is this?") in which the immense majority of students also answered according to the realistic conception: they mentioned the referent (a cell) instead of mentioning the representation (e.g., the photograph of a cell). However, there are studies which consider other possible explanations. Studies with children on the early differentiation between different notations (drawings and words) (Karmiloff-Smith, 1992) consider that children use the indefinite article to state what appears in a drawing (e.g., given a drawing of a horse they would say "a horse"); however, when they have to say what is in the word horse they would directly say "horse", without the indefinite article. According to Martí (2003) "In all drawings, the designation they make of the notation refers to the referent" (p. 74). Therefore, we are not certain that the answers found can be interpreted as the possession of a realistic conception or as a tendency to name the referent of visual-spatial representations.

Secondly, we stated the idea that there is an age/educational level-related progression from the realistic to the constructivist, via the interpretative realistic conceptions, on the one hand, and that students with specific instruction in biology were likely to show more constructivist conceptions than the group without that specific instruction, on the other. We found that the youngest group (1ºCSE) had a realistic conception. The next age group, students from 3ºCSE, revealed interpretative realistic conceptions. Though this is a more complex conception, we should not overlook that this conception still assumes an epistemological realism. So, we could consider it an intermediate conception between realism as one extreme of the dimension and constructivism as the other extreme. Regarding the idea that groups with more instruction in biology (1ºA-NS) have a constructivist conception, this is not fully backed by the tasks employed in this study. We found more constructivist conceptions in the selection part than in the justification part in the Agreement Task. However, this difference can be explained by the nature of the two task requirements. A recognition task in the selection may facilitate the choice of the most complex conception, while the justification task demands more requirements in order to find arguments which support the chosen conception. In consequence, one can expect to find fewer constructivist conceptions in the justification than in the selection task. This could indicate the difficulty of acquiring a constructivist conception in the processing of visual-spatial images even after having received specific instruction, as other studies have shown (e.g., Mason, 2002; Pérez-Echeverría et al., 2001).

The third question was about whether the students believe that certain innate capacities are necessary to interpret images and whether these images do not need to be taught, compared with the same conceptions about scientific knowledge. The data showed differences among the 1ºCSE and 3ºCSE and 1ºA-NS groups; the first group showed more innate scores in the Image Questionnaire than the second and third groups do. However, in general terms, comparing both questionnaires on the Innate-Learned scale although the 1ºCSE group revealed more innate conceptions than the 3ºCSE group, we also found that, overall, there was a higher score at the innate extreme of the Natural Sciences Questionnaire than in the Image Questionnaire, which does not confirm the proposed idea. Perhaps we have to analyze to what extent the formulation of items, their number and the way to measure them in this study is a correct instrument to assess these conceptions which often remain implicit.

Why do participants in this study show a realistic conception of the nature of a visual-spatial representation such as a photomicrograph? From our perspective, people assume realism between the image and its referent because of the embodied nature (Pozo & Gómez, 2005) of their implicit representations and the supremacy of perceptive aspects of the cognitive system. The presence of these restrictions makes it difficult to learn science due to the necessity of understanding images as representational systems. In the words of Martí and Pozo (2000):

> The use of any external representation presupposes that the subject realises that the meaning of this particular object does not arise from the object in itself but rather its representative potential. It is necessary for the subject to realise that the external representation is instead of something else and that it is a model of this reality (p. 28).

In other words, this would imply making use of the representative function of images as external systems of representation. Teaching how to read an image needs to explicitly encourage understanding the constructive nature of images as instruments of representation, learning and generation of new knowledge. This is only possible by means of a *graphicacy* or visual-spatial literacy, that is, teachers should specifically work with their students on interpretation and use of visual-spatial representations, helping them to decode graphical messages autonomously instead of being simply carried away by the impact, apparent simplicity, and immediacy of the image.

In conclusion, this study provides an initial attempt to empirically test the conceptions in the domain of scientific images. The results obtained must be considered tentative due to the exclusive use of one type of image, so that the generalization to all biological images could be risky. The tasks and instruments used to measure these conceptions need further research. We also need to assess to what extent some instruments are more suitable to identify the nature of the students' conceptions than others (e. g., Likert scale vs. open-ended task or selection vs. justification task). Besides, it would be necessary to include more types of visual representations such as diagrams, dynamic visualizations, and other populations such as teachers.

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Appendix A

Items of the Natural Sciences Questionnaire

Items of Realistic Scale:

Item nº 1- In most cases, scientists can clearly state what is actually happening once the facts and details are known.

Item nº 4 - A discovery or proven scientific law is and always will be true.

Item nº 18- Scientists see facts as they are and for this reason they can explain the truth to us.

Item nº 22- If two scientists argue and give different explanations on a fact of nature, at least one of them will be mistaken.

Items of Constructivist Scale:

Item nº 3- There is no scientific statement which is true in itself as each scientist has his/her own experience, but not all statements made by scientists are equally valid and acceptable.

Item nº 6- The effort of scientists may attain an increasingly more approximate knowledge of what occurs in nature, but they will never be sure of their theories.

Item nº 16- When two scientists argue and disagree on a topic, both stances may be valid and reasonable; they have to come to an agreement.

Items of Innate-Learned Scale

Item nº 7- There are people who are born with special skills for the sciences.

Item nº 15- Intelligent people are those who best understand scientific matters.

Item nº 17- To a great extent, scientific laws arise in or are discovered within ourselves; we don't need to be taught these laws.

Items of the Image Questionnaire

1. To understand an image of a cell well, we have to be intelligent.
2. The image of a cell reveals a way of understanding what a cell is like, but biologists may never be sure that this image is the true one.
3. Good images of a cell are those which reliably and exactly reflect what a cell is.
4. If two biologists argue on what is seen in a cell's image, both stances may be valid and reasonable.
5. The scientific images of the cell aim to report what a cell is like, but we cannot explain what a cell is like on the basis of this image.
6. Although we see a cell through a microscope, we cannot be sure what the cell is like.
7. I think the realistic images of the cell are better because they show what the cell is like.
8. There are no correct or incorrect images of a cell as this depends on several factors, for example, the purpose we wish to use it for, whom it is aimed at, etc.
9. To interpret the image of a cell, we have to have good visual-spatial capability.
10. The presence of the cell is only revealed when we see a photograph.
11. A certain image of a cell is a way to explain what a cell is and not just a description of what a cell is like.
12. By observing the above image, we can clearly know what a cell is like.
13. Before viewing a cell through the microscope, biologists had already traced images of the cell.

14. If two biologists are arguing about the image of a cell they are looking at and they give explanations on this, one of them will be mistaken.
15. The image of the cell reveals a representation of the cell to us but never what a cell is really like.
16. If we cannot see the cell or do not have an image of the cell, we cannot know with certainty what it is like.
17. It is sufficient to look at a cell's image to understand it, and it is not necessary for us to be taught to look at it.

Questions of Observe this Image Task

1. What appears in the image?
2. How do you think this image has been obtained?
3. Can the image be presented in a different way? Why?
4. Imagine that two biologists who are studying and researching on the cell have to draw a cell they are observing through the microscope. What do you think their drawings would be like? Will they look the same or different? Why?
5. How can you know (or what would you do to know) who has drawn the cell in a better way?

Appendix B

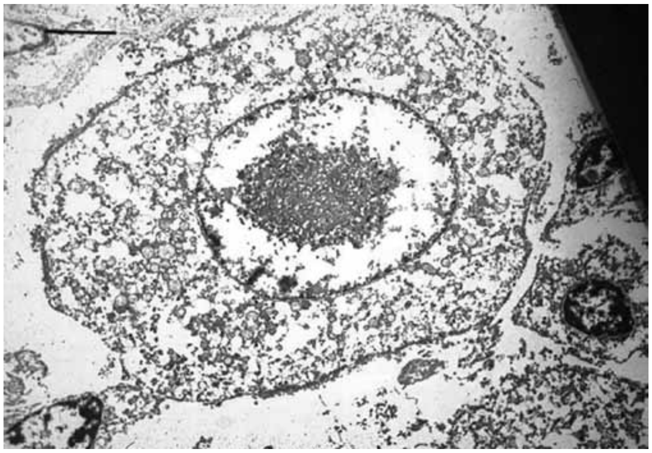

Figure 1. *Cell Image*

Note. This image is an adaptation from "Cell photomicrograph". (n.d.). Retrieved from http://escuela.med.puc.cl.