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Author: Jiménez-Aleixandre, M.P. & Díaz-Bustamante, J.

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Drawing and Slicing Cells

M.P. Jiménez-Aleixandre and J. Díaz-Bustamante. University of Santiago, Spain

1 INTRODUCTION: IMAGES, PICTURES AND GRAPHIC REPRESENTATIONS IN BIOLOGY

The teaching and learning of Biology relies strongly upon the use and interpretation of pictures, drawings and all sorts of iconic representations; it would be difficult to imagine teaching Biology without using them. Any Biology textbook contains a great number of graphic representations; for instance Carrick (quoted by Reid & Miller 1980) found in British textbooks of the 70's more than one every two pages. They range from photographs, drawings, electron micrographs, to outlines and other images, attempting to represent a wide range of scales, sections and idealizations of living beings. At the same time an important part of Biology courses consists of laboratory practical experience, including exercises with direct observation of samples, or by means of a microscope, and drawing these samples.

Biology teachers often mention the problems pupils have when they are asked to interpret and draw observed samples; and refer to similar problems when observing and interpreting images in textbooks. Hodson (1986) referring to APU findings, notes that children infra-utilize their senses, pointing out that they do not make detailed observations unless their attention is carefully focused, and that they do not readily identify significant relationships between observations without considerable guidance. Given this, one would expect a certain amount of research devoted to these difficulties, but a literature search in databases and in the major journals shows a relatively low number of papers concerning image interpretation in Biology. Maybe one explanation for this is that the difficulties seem to affect young pupils, whereas at the University level most students are presumed to be able to make adequate observations and drawings. Another explanation might be that, since research in Biology Education is relatively less developed than that of Physic Education, the lines of research of the latter years have been focused on concept learning, and of course in Physic Education pictures and images play a less important role than in Biology Education.

Some of the questions explored in the literature include: the role of colour and of other parameters such as field depth or figure-ground differentiation in the construction of illustrations, the transmission of information, the recollection of visual content, and what has been called the 'picture superiority effect' (Reid 1984, 1990 a & b, Reid & Miller 1980) in the context of the relative importance of text and images. Russell-Gebbett (1984, 1985), Macnab and Johnstone (1990), and Macnab, Hansell and Johnstone (1991) have investigated spatial skills and strategies in the perception of three-dimensional structures in Biology. Garvin and Boyd (1990) suggest a number of techniques aimed at developing skills related to observing, recording, and interpreting in Biology, in a book oriented towards the examinations of the Advanced GCE in Great Britain.

Our study attempts to identify the skills necessary for interpreting biological structures, in the context of practical work, and the problems that Secondary School and University students experience for their acquisition; and also the ways to assess these skills. In particular we are interested in the skills associated with interpreting cell drawings, and observing samples of cells and tissues through the microscope. Cell Biology is an important part of curricula for Secondary Schools in most countries, and its study depends upon the use of cell micrographs and drawings.

In this paper we present part of our work, consisting of the analysis of cell drawings by 9th and 11th graders, and by student teachers at the University School of Education. The following section deals with the methods used in the study, afterwhich we present some results of the analysis. In the last section these results, and some educational implications are discussed.

2 METHOD

Research questions

We had attempted to explore two general questions, which are subdivided in five research questions:

- General question A: Which, of the general features of a cell, are pupils able to represent in a drawing?. In particular,

1 Is it a three-dimensional (3-D) or a two-dimensional (2-D) representation?

2 Does it represent a particular type of cell (e. g. animal or vegetal), or an idealized one?.

3 What is its structure and how many elements of the cell are represented?

- General question B: Are the students able to represent a section of the cell? In particular,

4 Is it a section of a three-dimensional (3-D) cell, or of a two-dimensional (2-D) one?

5 Are the sections of structures accurately represented, e.g. are the elements represented as embedded in the cytoplasm or just lying on the surface?

Sample

A total of 274 people participated in this study: both High school students enrolled in courses of 9th and 11th grade, and student teachers in their Second year at the University School of Education. All the students attending the courses participate in it. Concerning the groups, it is an occasional sample, the election being related to the interest of the teachers in Biology learning.

The students in the 9th grade amounted to 62, constituting the two intact classes of this grade at the only State High School in a small village, aged between 14 and 15 years. The students in the 11th grade were 165, and they represent all the five classes at one of the State High Schools located in

Santiago, aged between 16 and 17 years. The ratio male: female of these groups are aproximately 1:1.

The 47 student teachers in the School of Educations were enrolled in a Biology course during their Second year of studies towards the Primary Teacher Degree, which is a three year program. Representing a less homogeneous group, the majority aged between 19 and 20 among a wider range, and the female: male ratio was aproximately 2:1.

In the Spanish curricula cell organisation is studied from the 6th grade on, so it can be assumed that all of them had studied it at different levels. Concerning their previous experience with practical work, the students in the 11th grade and the student teachers at the School of Education had all observed cells in the laboratory in previous courses. This is less certain in terms of the 9th grade students, since the High School they attend brings them together in this 9th grade, although they come from a variety of Lower Secondary Schools.

Instrument: Draw a cell

The instrument is a drawing test, consisting of two tasks administered consecutively. So, once they had completed task 1, they were asked to complete task 2. Task 1 was related to research question A, about their idea of a cell, and task 2 was related to research question B, about their ability to mentally manipulate a drawing of a cell. Tasks involving the production of drawings by students have been used too by Russell-Gebbett (1984) when studying problems related to the understanding of 3-D structures in Biology.

In task 1 they were given a sheet of paper, in which they were asked "to draw a cell, indicating its different elements". Instructions were also given verbally by their own teacher, telling them that the drawing was to represent their idea of the cell, with a statement similar to the following:

"When you think about a cell, you imagine something, and I want you to try your best and draw this *something*, as detailed as possible."

They also were told that they should do it on their own, without copying one another, or from the book.

In task 2 they were given another sheet of paper, and asked to open their own textbooks, in a particular page, where there was a drawing of a cell, then they were asked to represent "how would this cell look if it were cut it in half". As the student teachers lacked a common textbook, they were given a drawing of a cell with two lines, A and B, across it (see figure 9), and asked to draw how it would look if it were cut along line A, and along line B.

The tasks were completed as the first activity during the sessions devoted to the study of the cell in each course, and students spent a whole class session, about 50 minutes to perform both. No limitations were set regarding the space, so they could represent the cell in the size that they wanted. They were asked to use a ball-point or felt-tip pen, not pencil, to facilitate the scanning of the drawings.

The analysis of the drawings

The analysis was oriented to answer the research questions. For each question the drawings were grouped according to their ressemblance in loose categories, then, after seeing all of them, the final categories were established as seen in the tables. Some drawings, representative of the different categories were scanned, and a selection of these appears in the figures.

Such analysis is a complex task, and, as other qualitative metholologies, involves a considerable amount of subjectivity. Once the preliminar categories were established by the main researcher (Díaz), a representative sample of the drawings was analyzed independently by other two researchers, and the results showed an agreement of 86% among the three for the assignement of the drawings to the different categories.

We present the results of each task separately, beginning with task 1.

3 RESULTS FROM TASK 1: DRAWING A CELL

The analysis was oriented to answer research questions 1, 2 and 3. A selection of the drawings appears in figures 1 to 7. As a general comment on the task it can be said that it offered no great difficulties for students from the 11th grade, nor for student teachers. Among 9th graders there was an important percentage (19 %) who were not able to perform it. Also it has to be said that there were no observed differences between gender groups. A summary of results can be seen in tables 1, 2 and 3.

Table 1. 3-D and 2-D representations of a cell

	9th grade (N=62)		11th grade (N=165)		Student Teachers (N=47)	
	%	n	%	n	%	n
Do not draw it	19%	12	0%	0	0%	0
Draw it	81%	50	100%	165	100%	47
flat 2-D cell	77%	48	97%	160	98%	46
3-D cell	3%	2	3%	5	2%	1

Research question 1: Is it a three-dimensional (3-D) or a two-dimensional (2-D) representation?

As seen in table 1, a great majority of the drawings in the three levels are flat 2-D cells, such as figures 1, 2 and 3. Only a few students, 2 from the 9th grade, 5 from the 11th grade and 1 student teacher, which represents approximately 3 % of the total sample, represented a cell with volume, in three dimensions. As an example, the drawing of a student teacher appears in figure 4.

Research question 2: Does it represent a particular type of cell (e.g. animal or vegetal), or an idealized one?

The results shown in table 2, indicate that most pupils draw what could be described as a transversal section, or polar projection of an idealized "basic" type of cell, such as the drawings reproduced in figures 1 to 4. No mention is made to the existence of different cell types, or clarifications of the type or the particular cell presented. There are some exceptions, for instance attributing animal or vegetal type to a drawing, even if it doesn't bear any features that could justify this attribution. Such is the case of the cell in figure 5 labelled "animal cell".

A few cases offer drawings in which it is possible to identify or imagine a particular type of cell not corresponding to the "basic" model. For instance, a pupil from grade 9th drew the cell reproduced in figure 6, which could be due to previous microscopic observation or textbook representation. In particular it seems to correspond to a plant cell, such as onion skin; although in this case there is no label referring to cell type. Also the drawing made by a student teacher shown in figure 7, included a note indicating that it was a bacteria.

Table 2. Cell type

	9th grade (N=62)		11th grade (N=165)		Student Teachers (N=47)	
	%	n	%	n	%	n
idealized type	77%	48	97%	161	92%	43
Plant cell	3%	2	2%	3	4%	2
Animal cell	0%	0	1%	1	2%	1
Prokaryote cell	0%	0	0%	0	2%	1

Research question 3: What is its structure, and how many elements of the cell are represented?

Table 3 gives a summary of results. Some features that characterize the drawings are:

- The majority represent the cell as consisting in three or four concentric circles, characteristic of a model that could be called "fried egg", (e.g. the figures 1 and 2). More than 50 % of the three groups represent the cell membrane with two concentric circles, sometimes without any name, (e.g. in figure 1); sometimes with a common name, (e.g. in figures 3 and 4); sometimes labelling one "membrane" and the other "wall" as in figure 2, but without maintaining the real order, so it seems a rather arbitrary attribution.

Table 3. Cell structure and elements represented

	9th grade (N=62)		11th grade (N=165)		Student Teachers (N=47)	
	%	n	%	n	%	n
Structure						
Membrane represented by two circles	53%	33	54%	89	62%	29
Nucleus represented by a circle	79%	49	72%	119	66%	31
Nuclear membrane as a circle	0%	0	20%	34	19%	9
Nucleolus represented by a circle	6%	4	19%	31	28%	13
Cytoplasm as a blank space between membrane and nucleus	29%	18	80%	132	62%	29
Elements						
Mitochondria and/or chloroplast with cristae or lamellae	8%	5	24%	40	38%	18
Centriole represented by a cylinder	0%	0	5%	9	17%	8
Ribosomes with two subunits	2%	1	5%	7	9%	4
Number of elements						
Number of structures and organelles accurately drawn	2.1 per student		4.0 per student		6.1 per student	
Number of structures and organelles just mentioned	0.9 per student		2.6 per student		1.2 per student	

- More than 2/3 of the students of all the groups drew a little circle inside the others to represent the nucleus, and sometimes labelled it "nuclear membrane". Between the circles that could be identified with the membrane and the nucleus, they sometimes indicate the cytoplasm, e.g. in figure 2, inside which a series of objects were distribute evenly to represent cell organelles.

- Much less frequent is the presence of a fourth circle, a great deal smaller than the others, inside the circle representing the nucleus, with the label "nucleolus".

- The organelles and structures represented in most cases do not have a defined shape, instead they are circles of different sizes, ovals, and curved lines. For instance, mitochondria and Golgi apparatus are drawn as oval shapes; vacuoles and ribosomes as circles, the first being of bigger size; endoplasmic reticulum as curved lines , with simmetrical waves which delimit its cisternae, or other times as just two parallel curved lines. As seen in table 3 there is a certain number of students who represent some organelles in great detail, like those who draw mitochondria and chloroplast with a double membrane and cristae, (e.g. figure 3 by a student teacher); or centrioles as a cylinder consisting of filaments, ribosomes with two subunits etc.

- The number of elements represented is rather small. Altogether the students in the sample drew about 30 different elements, but the mean number of elements representd by each student, as seen in table 3, varies from 2.1 for the 9th grade to 6.1 in the case of the student teachers.

- In the 9th grade the great majority of the pupils draw and properly identify only two elements, membrane and nucleus, e.g. figure 6, where the cytoplasm is labelled "cell tissue"; some of them also identify the cytoplasm; in other cases they draw three elements but change their order or position, for instance the wall inside the membrane, or if they draw organelles, it is not possible do identify them; for instance the things labelled "mitochondria", "Golgi apparatus" and "chloroplast" in figure 1.

- For the 11th grade group the mean number of elements represented was 4: membrane, cytoplasm, nucleus and some of the following: mitochondria, ribosomes, Golgi apparatus or vacuola. The student teachers drew and identified around 6, the same as the students of 11th grade, with the addition of endoplasmic reticulum and centrioles.

- Sometimes the students recall a term or name, but they are not able to draw it. The proportion of these terms that they quote without drawing them appears in table 3.

In summary, the majority represent a two-dimensional cell, rather stereotypic, not one of a particular type, and consisting of concentric circles; they usually represent membrane, cytoplasm and nucleus; sometimes the wall; and only in a few occassions other elements as mitochondria, ribosomes, vacuola etc.

4 RESULTS FROM TASK 2: SLICING A CELL

The instrument used for this task included a drawing of the cell which had to be cut. An instance of one of the textbook's images used by students of 9th and 11th grade appears in figure 8 (the original was in colour); and the one used by student teachers in figure 9. Students were asked to represent how would the cell look if they cut it. A summary of results appears in table 4.

The analysis was oriented to answer research questions 4 and 5. Some drawings representative of the different categories appear in figures 10 to 16.

The task of representing a section of the cell offered more difficulties to pupils than task 1. As seen in table 4, between a 11 % and 17 % of the students were not able to complete it; no differences were found between girls and boys. The task was also difficult to analyze, because, since the test was realized as part of the normal classroom instruction, they were asked to use their own books, which caused a variety of cell images to be used as a starting point.

Research question 4: is it a section of a three-dimensional (3-D) cell, or of a two-dimensional (2-D) one?

As seen in table 4, the drawings were classified under 6 categories, from which only the first one corresponds to a section of a 2-D cell . The other five, corresponding to the great majority of drawings, are different sections of cells with three dimensions, which we ordered hierarchically, with category 2 being the "least" 3-D, as discussed below.

Table 4. Cell sections

	9th grade (N=62)		11th grade (N=165)		St. Teachers (N=47)	
	%	n	%	n	%	n
do not complete the task	13 %	8	11 %	18	17 %	8
2-D cell, 2-D section (e.g. figure 10)	3%	2	7%	11	19 %	9
"coin" section of a 3-D cell, (e.g. figure 11)	3%	2	5%	9	19 %	9
"tray" section of a 3-D cell, (e.g. figure 12)	5%	3	3%	5	13 %	5
standard section of a 3-D cell, (e.g. figure 13)	24 %	15	32 %	52	21 %	10
3-D cell, 3-D section (e.g. figure 14)	8%	5	15 %	25	6%	3
3-D cell, complex 3-D section (e.g. figure 15)	44 %	27	27 %	45	6%	3
Spheric elements represented as cilindric (e. g. figure 16)	11 %	7	5%	9	2%	1

- Category 1, flat, 2-D cell and 2-D section: one example is reproduced in figure 10. These are drawings in which the student represents the whole surface of the section of the cell from the text (compare figure 10 with figure 8), when the text has a 3-D image; or reproduces the drawing when it has a 2-D image, whereupon the surface is divided in two, with a "gap"separating both halves . The highest percentage of these sections of 2-D cells was found among student teachers.

- Category 2, "coin" section of a 3-D cell; category 3, "tray" section of a 3-D cell; and category 4, "standard" section of a 3-D cell, all correspond to drawings representing a section of the third plane as they imagined it. Such were classified as 3-D cells because they attempt to represent a cell with volume, although only two dimensions are presented in the drawings. We called category 2, "coin" section of a 3-D cell, (e.g. figure 11) because it looks like a section of a cell which would have the shape of a coin, with the structures aligned along the middle; as seen in table 4 is only frequent among student teachers. Category 3, "tray" section of a 3-D cell, (e.g. figure 12) corresponds to a better image of an ovoid cell, but the structures and elements are situated only near the upper surface, like dishes on a tray, and not distributed. Category 4, "standard" section of a 3-D cell, (e.g. figure 13) was called as such because we consider this to be the simplest correct solution to the task, being a section of a prototypical cell, and as seen in table 4 its percentage was high for all three levels.

- Category 5, 3-D cell, 3-D section; and category 6, 3-D cell, complex 3-D section, correspond, not only to having drawn a three dimensional cell, but also representing it in three dimensions, and the differences among both being the complexity of the representation. Thus, in category 5, 3-D cell, 3-D section (e.g. figure 14), the student represented the organelles distributed in the surface of the section, whereas in category 6, 3-D cell, complex 3-D section (e. g. figure 15), the drawing represents a section of a sphere such as a segment from an orange, with two visible section planes, so that the spatial distribution of the organelles is also represented. Some of the problems found in the drawings classified in these two categories are related to perspective, as shown for instance in the central drawing in figure 14, and the structures labelled as "Golgi apparatus" and "liposomes" in figure 15.

Research question 5: are the sections or structures accurately represented, e.g. are the elements represented as embedded in the cytoplasm, or just lying in the surface?

In part, research question 4 has answered this. As there is a great variety of drawings, we did not made different categories for this question, but it can be said that the degree of accuracy is quite low.

It also has to be noted the representation of spheric or almost spheric elements as if they were cylindric (see figure 16). As seen in table 4 the number of these is low, but we think it an interesting matter to reflect upon.

In summary we can say that the majority of students are able to represent a section of the cell, and that most sections seems to correspond to three dimensional cells.

5 Discussion of the results: skills in observing and drawing cells

This study is a part of a broader one in which we try to explore the interpretation of biological structures in the context of practical work. This involved also classroom observation and videotaping students in the laboratory; and its analysis, in relation to the analysis of the drawings they produced, which were to be part of a portfolio of each student. It constitutes an attempt to explore the images students have about the cell structure, and their communication skills for sharing information by means of drawings. We expect that this exploration will be an aid in further understanding their interpretations of the cell and of other biological structures.

Results of general question A: Which, of the general features of a cell, are pupils able to represent in a drawing?

With respect to the aspects considered in this question, we found that most students represent a 2-D cell, of an idealized "basic" type, representing its structure with circular concentric lines, and with few organelles in it.

Concerning the first research question, referring to the existence of two or three dimensions in the drawing, it is interesting to note that our results, (with only a 3 % of the students producing 3-D drawings), differ greatly from those of Caballer and Giménez (1993), where a sample of spanish students from the 8th grade responded to a written paper and pencil test, in which 52 % of them attributed three dimensions to the cells; however, the percentages of the youngest pupils not able to complete the task, are similar for both 9th grade and 8th grade students, 19 % and 21 % respectively, do not answer to the question.

In our opinion the fact that the proportion found in our sample is much lower could be related to the difficulties involved in reproducing a complex three dimensional drawing, and we must keep in mind that these difficulties exist even when just recalling the drawing, as Reid and Miller (1980) have shown; on the contrary, the students produce simple drawings, based on those commonly used by teachers on the blackboard, and even present in a great deal of textbooks. The possibility that the difficulties lie more on the drawing skills, than in the image they have about a cell is supported by the results of the second task, which show a majority of students producing sections of 3-D cells, as seen in table 4.

Concerning the second research question about the cell type, we suggest that there may be similar reasons, i.e. drawings employed both in textbooks and in classroom instruction, to explain why the majority of students produce a stereotypic "basic" cell. Unlike other Biology topics, such as plant nutrition, where their ideas could be related to everyday experience, their ideas about how a cell looks have their origin in the instruction received. Perhaps by modifying the task we could explore whether students are able to represent different cell types with a certain accuracy.

Concerning the third research question, the structure and elements represented, the drawings the students produce could also be considered a stereotype related to the model of concentric circles widely used in instruction. This "fried egg" model is seen in their representations of the membrane, cytoplasm and nucleus, and also in the drawings of the nuclear membrane and of the nucleolus produced by several 11th grade pupils, and by student teachers.

It strikes our attention that the cell membrane was represented by two concentric circles, in more than 50 % of all drawings, as seen in table 3. Some of the student teachers were interviewed about this, and they said they were trying to represent the Dawson and Danielli model of the membrane, although they did not say anything about this in the captions. Two of the student teachers produced drawings which included phospholipids. This mixture of different scales and levels of organisation, confusing cellular and molecular, as well as optic and electron microscope observations, could be related to the lack of a clear distinction in texts and instruction of those scales and levels. Another interpretation which has to be considered is that they are trying to limit the space the membrane occupies, by setting external and internal limits, and we must remember that in some cases the inner circle is labelled cytoplasm. When they draw a single circle for the membrane, we interpret that they treat it as a "wrapping" containing the cytoplasm.

The cytoplasm is represented as limited by the membrane and having the nucleus in the middle, where they draw the rest of the organelles, and even sometimes they fill this in with little dots. The nucleus is represented by a circle, and about the same percentage (20 %) of 11th graders and student teachers, labelled it as "nuclear membrane". In the sample of Caballer and Gimenez (1993), 36 % of the 8th graders mention the nucleus among the structures and elements of the cell, 23 % the cytoplasm, 13 % the mitochondria, and only 3 % the membrane (the same percentage the chloroplasts). In our case the percentages of elements drawn or mentioned is higher, for instance, more than two thirds draw the nucleus, although the organelles are just mentioned, not drawn, by many, as seen in table 3. Perhaps they just recall the name but do not know what the organelle is or the structure to which it belongs.

In some cases there are organelles represented in great detail, particularly mitochondria, chloroplasts, centrioles and ribosomes, drawn as if they corresponded to interpretations of electron micrographs, with a degree of resolution, and even a size contrasting with other organelles drawn as if representing observations through a conventional microscope. As mentioned before we attribute this mixture to the lack of a clear distinction established in instruction, and we believe that this deserves more attention, as it results in a false image of the cell. A similar criticism could be done of some coloured drawings that assign particular colours to the organelles, producing a confusion, as Storey (1990) notes, or at best, not helping students to construct an adequate model of the cell.

Results of general question B: Are the students able to represent a section of the cell?

The answer to this question is affirmative, as only a reduced percentage, between 11 % and 17 % were not able to complete the task, and also it has to be noted that more than 60 % of the students in the three levels drew sections of three dimensional cells.

Concerning the fourth research question, whether the section is from a 2-D or from a 3-D cell, we found a small percentage of the secondary school students, and a relatively higher one (19 %) of student teachers who represented a flat section of a cell with only two dimensions, (by simply dividing the cell they are given in two halves, separated by a gap). We have three possible explanations for this, assuming they know that the cell has volume: 1) that they did not understand the task, simple as it may seem; 2) that they do not pay heed to the third dimension because it is not signifiant in their conception about the cell (in the same manner that many teachers and books only offer a flat image of the cell although they *know* it being three dimensional); it must be said that all these students had produced a flat drawing in the first task; and 3) that they are not able to imagine the section, having difficulties similar to those mentioned by Macnab and Johnstone (1990) for representing sections. These students could be what Russell-Gebbet (1984) calls pupils weak in sectional shape abstraction. A fourth explanation also has to be considered, that they are not aware that the cell has three dimensions. To know which of those explanations correspond to each pupil, or to the highest proportion, we would need more detailed studies, including personal interviews.

A particular case is where 19 % of student teachers drew a 2-D cell. It is noteworthy that the cell they had as starting point was a flat 2 D one (see figure 9), but also that they are older, and have a better background in

Biology than the secondary school students. Following Macnab and Johnstone (1990) we could expect them to possess the skills required to produce a representation of a 3-D cell. As they failed to do so, we suggest that it turned out to be a more complex task to imagine a 3-D section from a 2-D representation of a cell, than from a 3-D representation like the one the students of 9th and 11th grade had.

Also it is interesting to discuss the second category: students who represent the section as a "coin", which we interpret as a lack of knowledge of the cell organisation, and even of the shape of the organelles, and again related to a poor understanding of the cell as a body with volume. These two categories, 1 and 2, show that there are many flaws in the conception that students have about the cell, and that we think would have been unadverted whithout this particular type of test.

The third category, the "tray" section, implies, in our opinion, a wrong appreciation of the spatial relations of the internal cell structures, imagined from different perspectives. This is another of the spatial skills involved in the understanding of 3-D structures in Biology (Russell-Gebbett 1984, 1985).

In the rest of the drawings classified under categories 4, 5 and 6, we think that there does exist a clear three dimensional conception of the cell, even in spite of the problems remaining about the shape or situation of the organelles. It has to be noted that, whereas the majority of the students produced 2-D drawings in the first task , and only 3 % a 3-D one, in the second task the majority produced sections of cells with three dimensions; one explanation may be that the task itself caused them to focus on the fact of the volume of the cell.

Concening to the fifth research question, related to an accurate representation of structures and organelles, this strongly depends on the type of section they had produced. In the flat, 2-D sections they reproduce the organelles just as they look in the drawing they were given, so there is not a chance of exploring the 3-D image they have about them. In the "coin" section, the organelles are represented as a cross view of the ones represented in the surface, situated in the cell profile, for instance in figure

11, part A, the cisterns in the Golgi apparatus are drawn as small circles, when they should look similar to their representation in the original (figure 9); the centriole is represented as a rectangle with dots inside, the rectangle representing the centrosphere, and the dots the microtubes.`

In the sections that we called complex, 3-D drawings and that involve a three dimensional representation of the structures, problems with the perspective sometimes appear (see for instance figure 15), and also with the representation of the shape of certain structures (e.g. figure 16), resulting in a mixture of accurate and inaccurate representations, which in the drawing reproduced seems to result in a projection towards the inside of the cell of what is perceived on the surface of the drawing, corresponding to what Russell-Gebbet (1984) called being weak in appreciation of internal relationships of parts of three dimensional structures.

Some educational implications

The results presented here are the preliminar part of our work, and some of the questions raised need to be studied in greater detail. We found some problems that could be related to the understanding of concepts and processes about cell organisation, to its structure and to the relations among organelles. These problems parallel the findings of other studies, e.g.Dreyfus and Jungwirth (1988, 1989) on the idea of the living cell as the basic unit of life, Smith (1991) on cell division, and Caballer and Gimenez (1993) on cell structure. In our opinion these problems are not only due to the difficulty in understanding concepts, but also due to the development of skills. If we want them to be familiar with cell images, they should perform a certain amount of microscope observations; nevertheless we found a high proportion (32 %) of University students in their second year specializing in Biology, who said that they had used the microscope for the first time at the University (Sahuquillo, Jiménez & Díaz 1993). Our suggestion is that the development of these specific skills should be considered seriously by teachers, and this implies not just writing this among the goals, but also designing carefully guided activities to promote such skills, and assessing them. For instance, we believe that most practical work with cell and tissue samples in Spain asks the pupils to just "observe", whereas our proposal is to set some problems, for instance:"why can you not see all the nucleus in the onion skin ?"

Another suggestion is related to substituting te stereotypic idealized, unique cell frequently represented in textbooks for a variety of different cell types, which, as Wandersee (1992) has shown for the difference among eucaryotic and procaryotic, can better promote the construction of an adequate model of the cell than a single one.

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Figure 1 – Cell Drawing by a 9th grader (B–15)

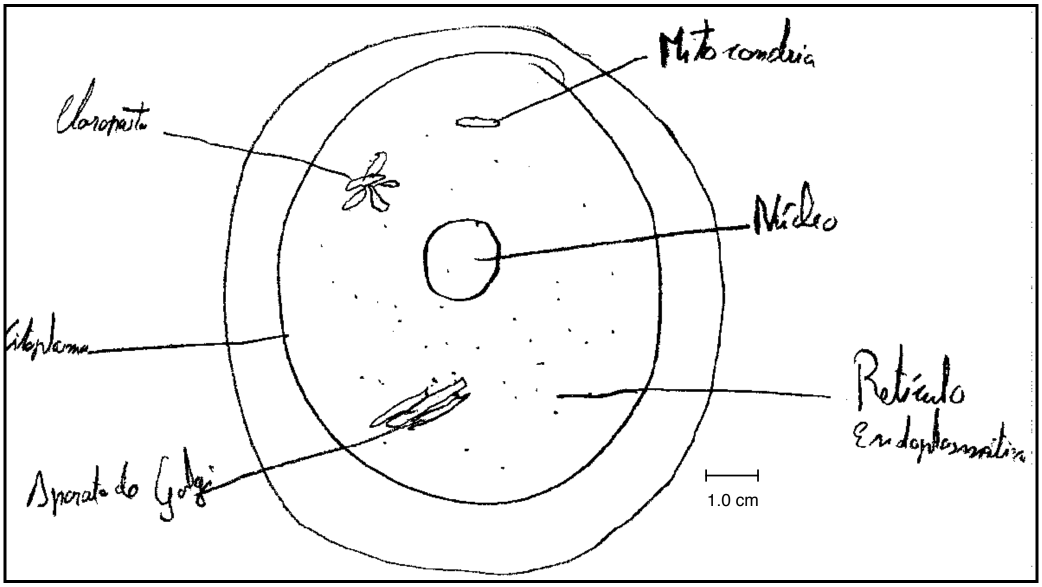

Figure 2 – Cell Drawing by a 11th grader (X–14)

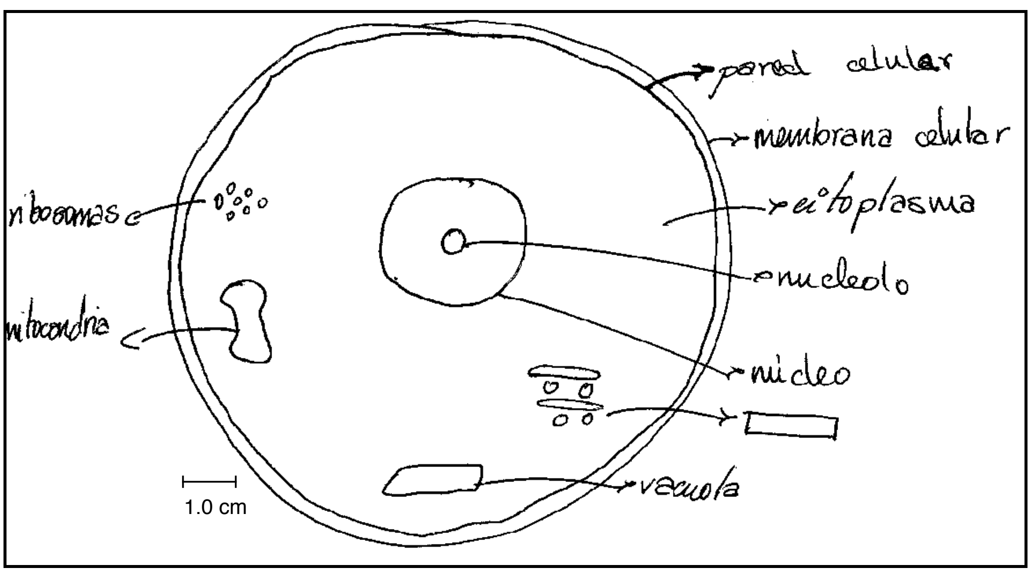

Figure 3 – Cell Drawing by a Student Teacher (M–31)

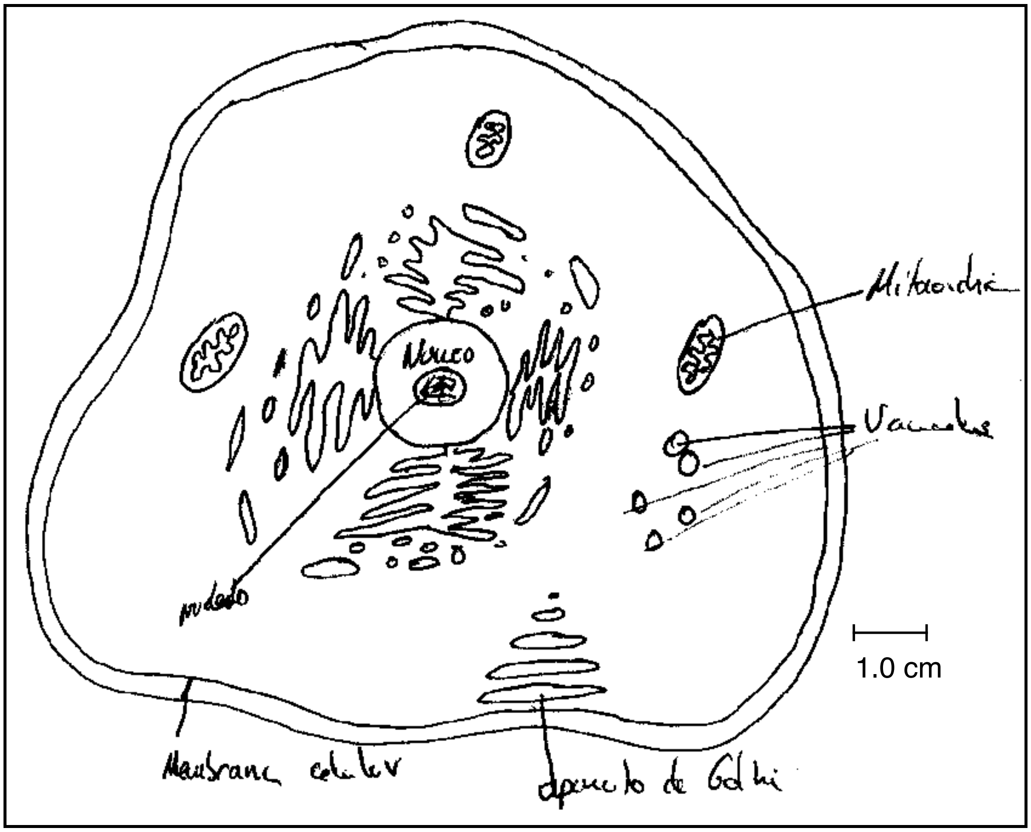

Figure 4 – Cell Drawing by a Student Teacher (M–36)

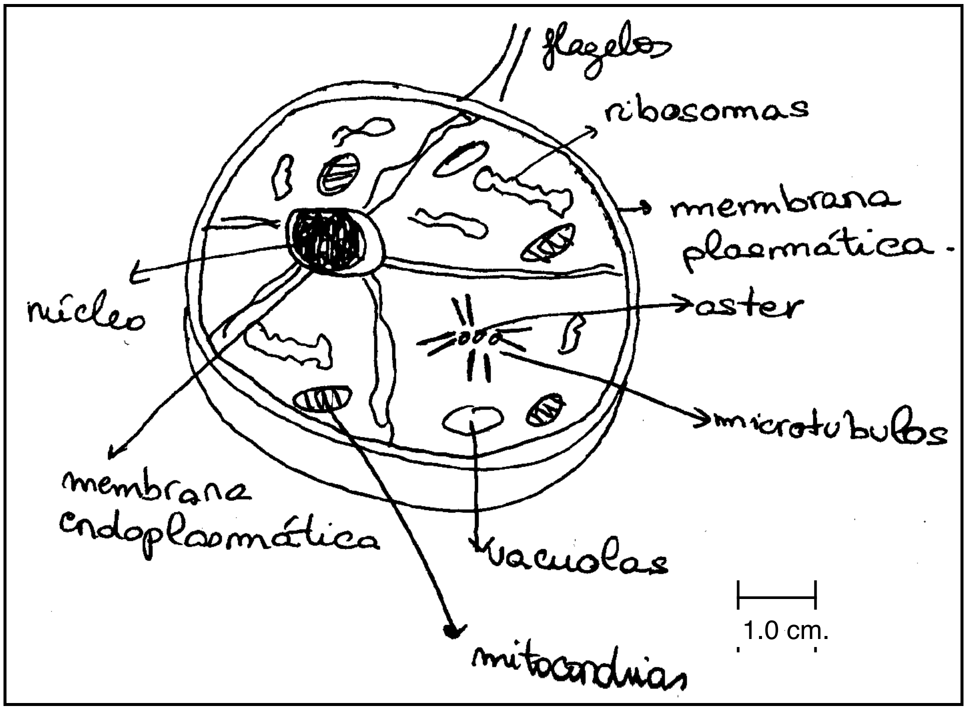

Figure 5 – Cell Drawing by a 11th grader (X–119)

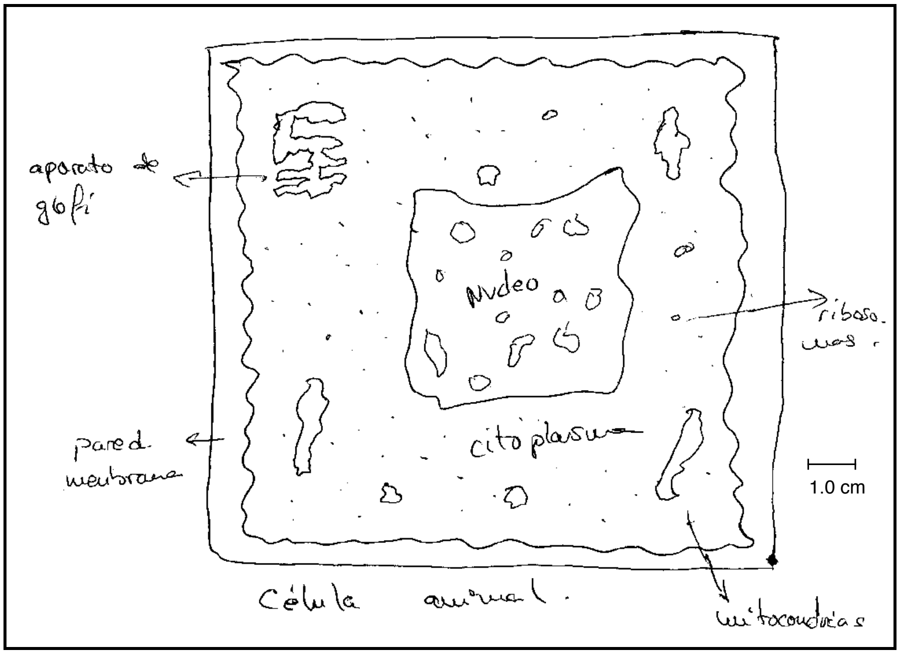

Figure 6 – Cell Drawing by a 9th grader (B–10)

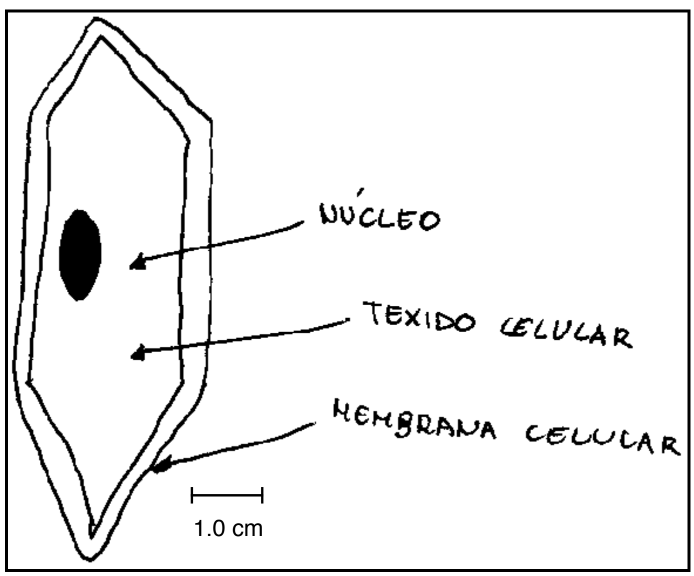

Figure 7– Dibujo de una célula procariota realizado por un alumno de Magisterio (M–47).

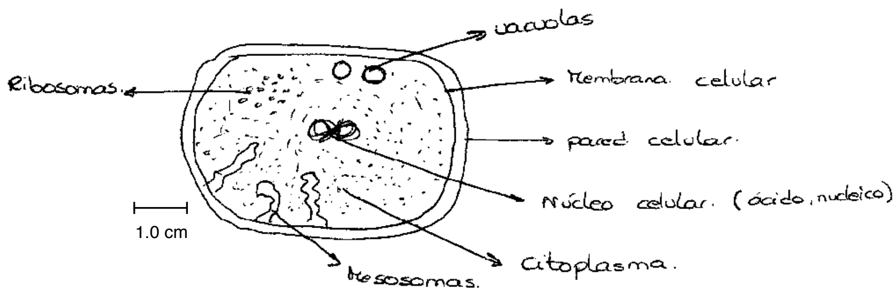

Figure 8. Instance of cell image provided for task 2, in 9th & 11th Grades

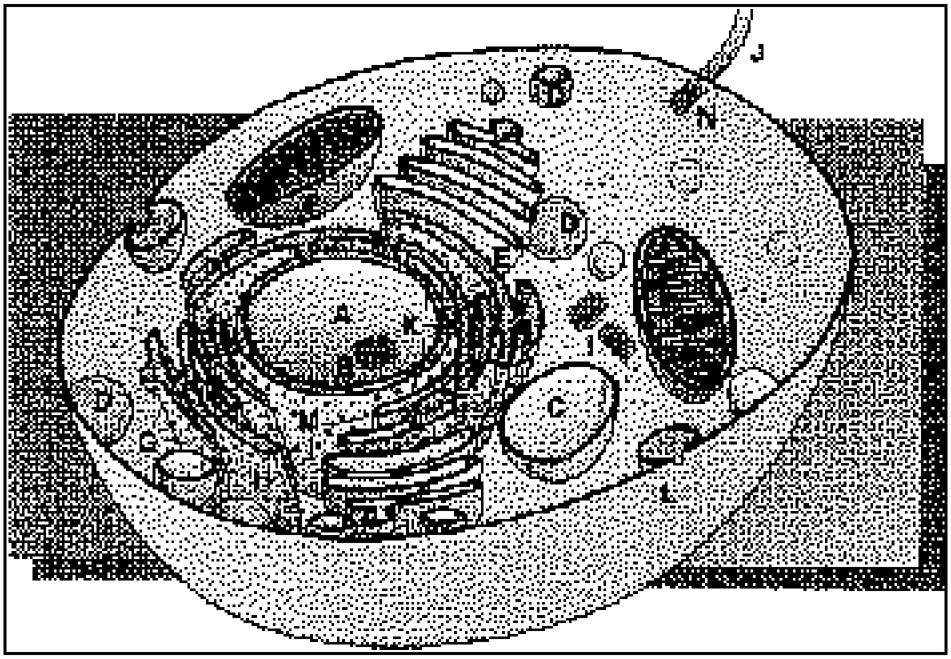

Figure 9.Cell image provided for task 2, to Student Teachers

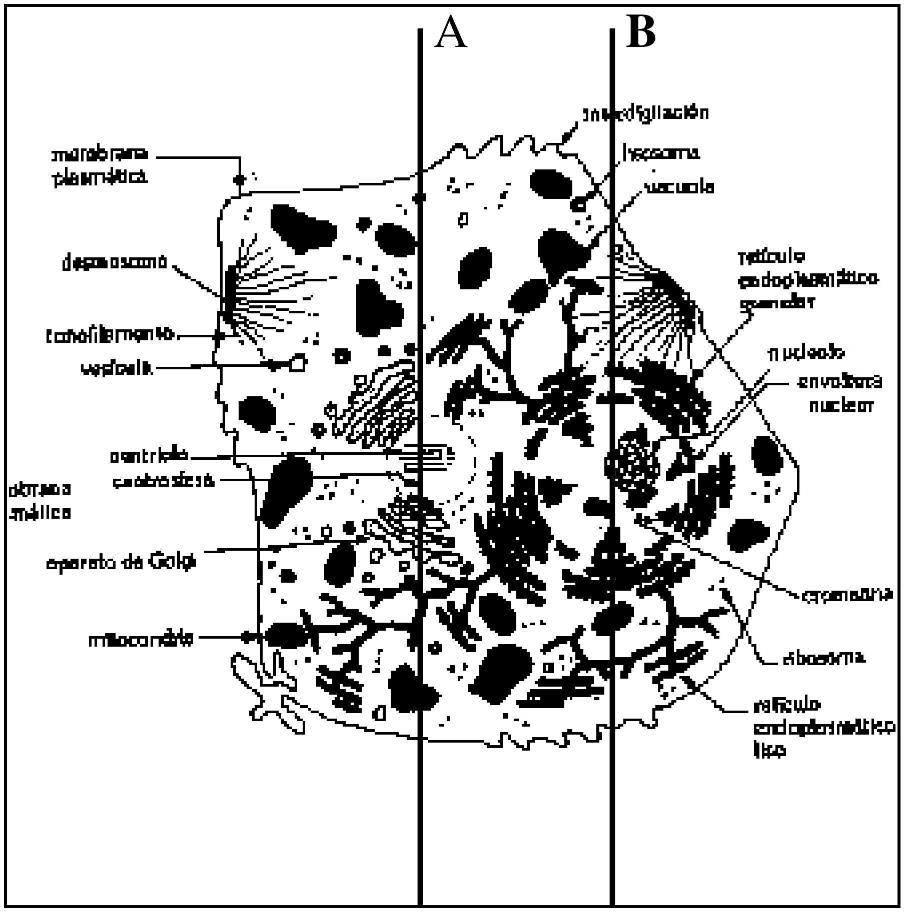

Figure 10. Cell Section by a 9th grader (B–35)

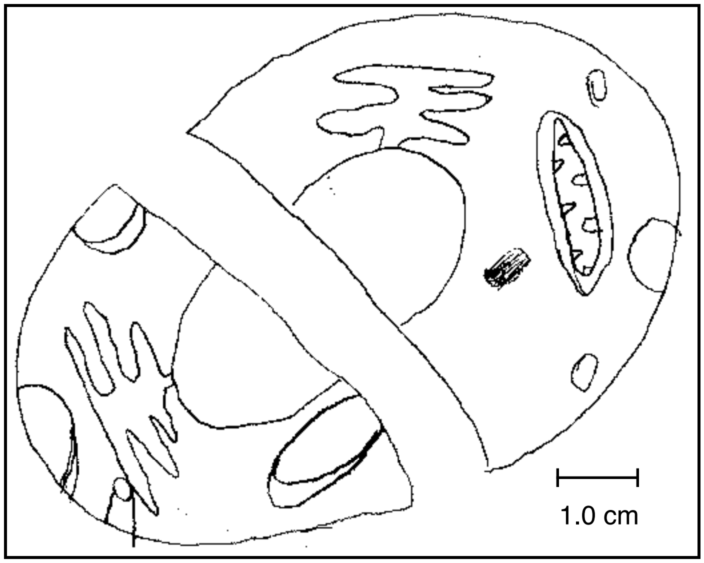

Figure 11. Cell Section by a Student Teacher (M–31)

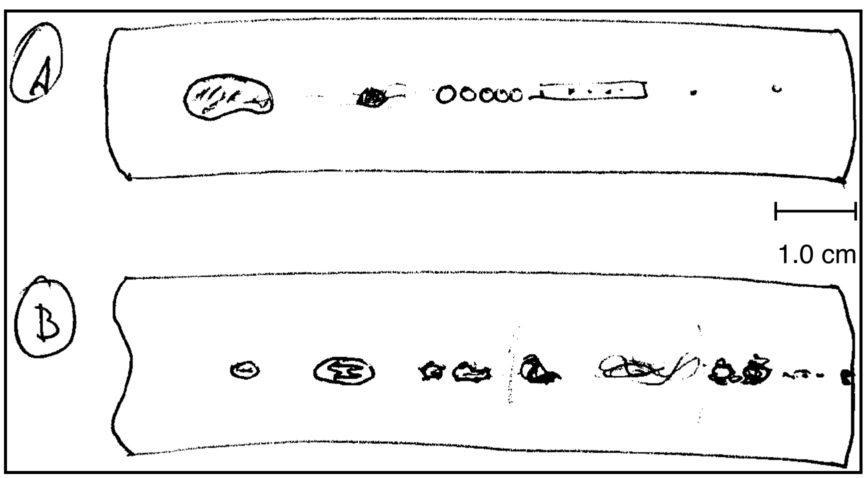

Figure 12. Cell Section by a 9th grader (B–30)

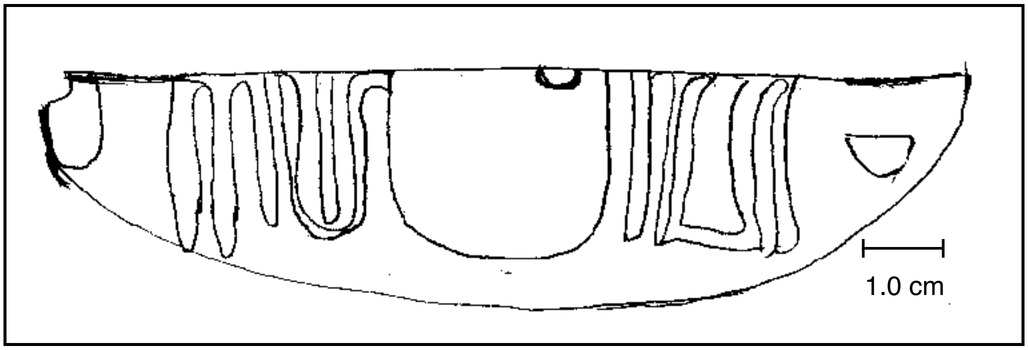

Figure 13. Cell Section by a 9th grader (B–46)

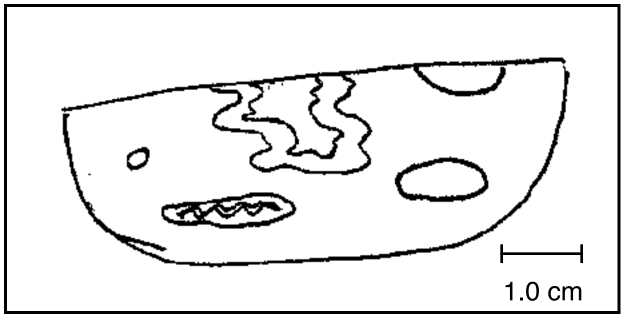

Figure 14. Cell Section by a Student Teacher (M–40)

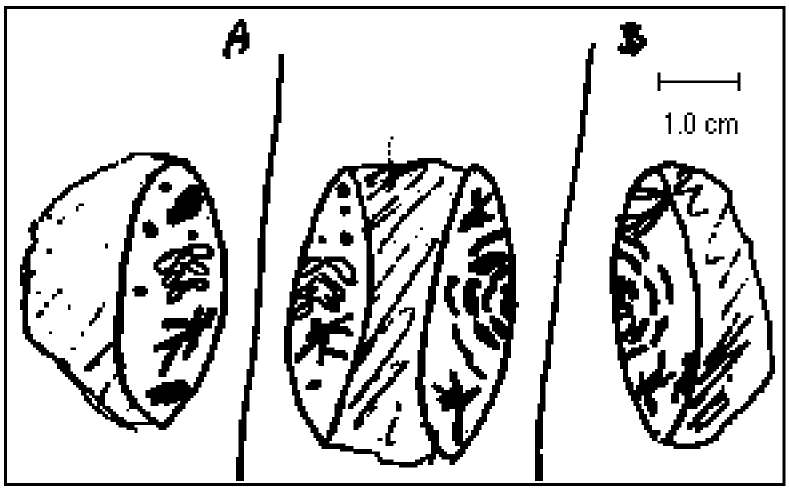

Figure 15. Cell Section by a 11th grader (X–13)

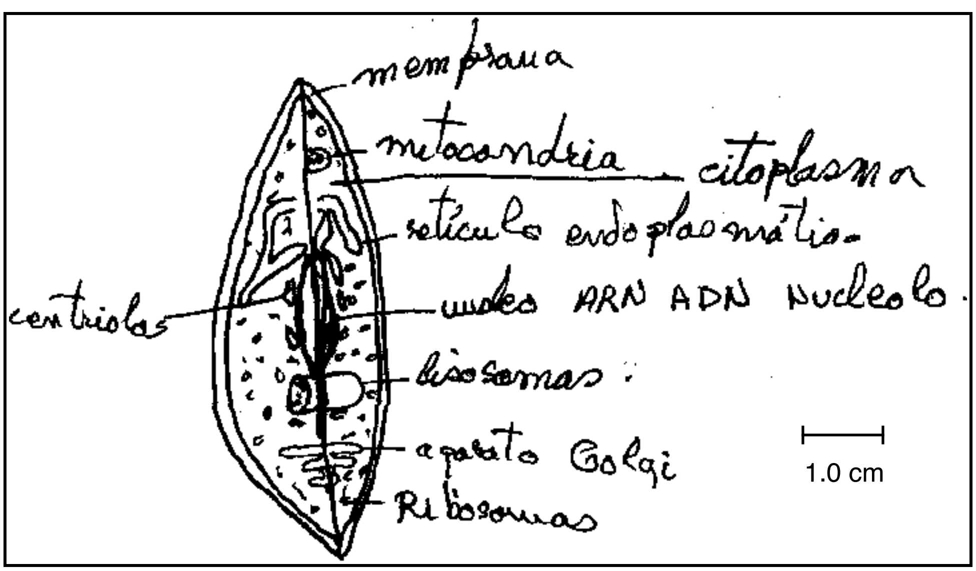

Figure 16 Cell Section by a 11th grader (X–127)