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UNIVERSITY STUDENTS' KNOWLEDGE AND MISCONCEPTIONS ABOUT CELL STRUCTURE AND FUNCTIONS

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Abstract:
This study aims to assess the level of understanding of biology students and to identify their misconceptions about cell concepts. Participants of the study (n=160) were students enrolled in biology undergraduate level. Data analysis showed that the students had cell-related misconceptions. The misconceptions were found in four basic competencies of the cell concepts. The most common misconceptions (55.68%) among students are those related to the relationship between the structure and function of the nucleus and endoplasmic reticulum. We denote that most of the students have assimilated the concepts related to the chemical constituents of the cell. There are several potential factors that cause the occurrence of misconceptions among the participants in this study, including low retention of knowledge obtained in previous school levels, lack of learning resources, incomprehensible terms, and low interest of biology students in cell concepts.

Keywords: cell biology, misconceptions, structure-functions

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1. Introduction

Biology is among the disciplines taught in primary school, it is a scientific discipline that is interested in the study of living beings and the environment in which they live. But the teaching of biology in general as a science for studying the life of living beings, given the great diversity of these, given their intimate connection to environmental conditions, and the many levels of the organization poses many difficulties for students and teachers (Tekkaya, 2002; Çmer, 2012; Lazarowitz, & Penso, 1995). All this supposes a very great complexity that requires an educational approach directed the rigor and imagination at all levels: primary, secondary, and university to ensure a good teaching of biology. This complexity of living beings has led to the subdivision of biology into several disciplines: cell biology, molecular biology, biochemistry, immunology, embryology, ecology, and genetics.

Cell biology, a central branch of biology which studies the unity of living things, has undergone major developments over the past twenty years thanks to technological advances in various fields (electron microscopy, biochemistry, immunology, etc.). This made possible the direct observations of cellular phenomena but also advances on a conceptual theoretical level. The study of cell biology should therefore be part of the basic science education of every citizen of the 21st century.

Cell in particular is a microscopic concept that generates various difficulties and learning obstacles in undergraduate students (Riemeier, & Gropengießer, 2008). It remains a science difficult to define, especially since the cell as a structural and functional unit is considered a metaphysical concept, not concrete, not visible, and linked to microscopic observation (Clement, 2007). This difficulty will undoubtedly create in the learners a false understanding of the basic concepts of cell biology and will emerge false ideas, erroneous conceptions, and unsurpassable misconceptions that block good learning in biology (Giordan, Girault & Clément, 1994). However, several studies that have focused on the teaching of cell biology and educational innovations have shown that this discipline generates learning difficulties for students, which will constitute potential obstacles to the assimilation and understanding of concepts of other biological disciplines (Tekkaya, et al., 2001; Cohen, & Yarden, 2009).

Furthermore, the main objective of science education research over the past three decades has been to identify student misconceptions in many areas. The term "misconceptions" was coined to describe alternative conceptions, naive ideas, or conceptions of science incompatible with concepts currently accepted by the scientific community. Student misconceptions are often deeply rooted barriers to the acquisition of scientific concepts, which prevent learning and remain even after instruction (teaching). Misconceptions are part of a larger knowledge system that involves many interrelated concepts that students use to make sense of their experiences. Students have misconceptions that were developed before and during their early school years (Bahar, 2003; Wandersee, et al., 1994; Dove, 1998; Driver, 1989).

Similarly, in biology, many studies have reported misconceptions about several concepts, for example, students manage to describe the processes of photosynthesis in the chloroplast and cellular respiration in the mitochondria but do not succeed to develop their functions or give the relationships between the two processes (Barak et al., 1999). Other studies have identified a common obstacle, that of confusion of the cell with its peripheral double membrane (Clement, 2007). Incomplete conceptual understandings of diffusion and osmosis were also identified among undergraduate students (Odom, & Barrow, 1995; Odom, 1995; Garvin-Doxas et al., 2007). Furthermore, the majority of students found topics such as genes, DNA, chromosomes, and cell division to be difficult to learn (Öztap et al., 2003); it turned out that the nucleus, its structure, and its functioning are notions perceived as being the most difficult for the students (Bahar et al., 1999). Indeed, the complex nature of cell biology is another reason why it is difficult to learn and teach (Bahar, 2003). The structure of cell biology content is complex and students must use this complex content to solve complex cell biology exercises. The concepts of cell biology refer to different levels of biological organization, and students have difficulty relating these different concepts and cytological and metabolic processes at these different levels. Several science researchers have noted that when the concepts and processes of content belong simultaneously to different organization levels, students have difficulty grasping that content. Some researchers distinguished the macroscopic, microscopic, and sub-microscopic levels when they studied the difficulties of learning the cellular and molecular aspects of cells among students (Marbach-Ad, & Stavy, 2000).

The prevalence of misconceptions among students is a serious barrier to learning cell biology. To promote effective and meaningful learning, we need to identify these misconceptions and find ways to correct or prevent them from happening. Misconceptions can arise when teaching fails to induce conceptual change in the student. Some prerequisite concepts are necessary for the learner to develop a real understanding of a given concept. If these do not exist, it would be difficult for the learner to understand the new concept. Teachers then can play an important role in teaching scientific concepts and students should acquire useful knowledge about the concepts of cell biology and should be able to use and apply basic biological concepts when approaching biological problems (Yusmina Hala et al., 2018).

Since the first cycle of the university is a central stage in the student's journey and also constitutes a barrier for thousands of students who are thrown out of university, it then becomes important to assess the learning that is based on how students learn science and how the university helps them to know how to use their knowledge in daily practice, as well as to assess the extent and the effectiveness of the reform carried out during the last decade and to see if their learning conforms with the objectives declared in official instructions. Hence the object of this research, which aims to assess knowledge, as well as identify the difficulties in learning essential concepts of cell biology among students in Morocco. This work could help cell biology teachers to gain insight into these difficulties in order to design teaching situations that allow students to overcome these difficulties. From all these elements emerges the problem of the present research which

the objective is to assess the knowledge of undergraduate students and to identify their misconceptions relating to the cell. Hence, this study was framed by the following research questions:

- What are the students' knowledge of cell' structure and functions?
- What are the students' misconceptions about cell' structure and functions?

2. Material and Methods

2.1 Research design

To study knowledge and misconceptions related to cell biology among university biology students, we used a survey research design. These research methods are suitable for this study because types of misconceptions are the key variables of this study.

2.2 Sample

This study took place at a large university in an introductory-level cell and molecular biology course intended for first-year students. The study sample consists of 160 students. The average age of students was 20.3 years (range 17 - 22). The majority of students were females (110 of 160). However, this study was not focused on gender differences. Participants previously had studied cell biology as a school subject during the first semester. They had learned basic notions about the structure and functions of cells components, namely the structure of the cell; the distinction between a prokaryotic cell and a eukaryotic cell, and between a plant cell and an animal cell; they had also learned the relationship between the structures and biological functions performed by cells. The cell biology course includes 28 h of lectures and 15 h for tutorials and practical work.

The authorization to survey students was obtained previously from the institution concerned. The survey was introduced by explaining the purpose and goals of the study. Participants were asked to participate and were informed of the guarantee of anonymity. Participants are also informed that those who give their consent are invited to complete the questionnaire. The survey was administered on paper; this was more time-consuming than electronic surveys but this method was chosen to increase response rates.

2.3 The questionnaire

To collect the data necessary for our survey, we used a questionnaire. The survey instrument was developed using student misconceptions identified in the literature (Chinnici, et al., 2004; Bennett, 1998; Odom, 1995).

The knowledge questions were graded by taking into account the orientation of the content of the curriculum of cell biology at a university in Morocco. Three hundred copies of the questionnaire were distributed according to the available means and access conditions (return rate was 53.3%). Participants completed the questions individually.

We used a questionnaire with multiple-choice questions. The questionnaire was pre-tested on a sample of 30 students from the Semlalia faculty of sciences (these students

have not participated in the final survey). Items are written in French. The best formulation was selected during a consensus meeting with content knowledge and French language experts. The validity of the instruments was established by subjecting the instruments to the judgment of experts in the field of cell biology and didactics of biology in the departments of Biology and Sciences Education in the Ecole Normale Superieure of Marrakech. To ensure the reliability of the instruments, a reliability coefficient was computed using the Cronbach Alpha method of reliability to establish the internal consistency of the instrument. In this case, the level of significance in which the instruments were adjudged reliable was 0.71.

The questionnaire contains forty-one questions. The survey questions were classified into three sections to facilitate understanding of the questions. In this article, we treat a part of the questionnaire (see Appendix for the full questionnaire). The questionnaire allowed the collection of information on the following elements:

- Students' background information (age, sex, university level, etc.), this part contains five questions.
- Students' perceptions about the difficulty and importance of cell biology learning
- Students' general knowledge of cell biology. This part contains thirty-seven questions, divided into two themes:
    - Chemical constituents of cell: with 15 questions (Proteins, Carbohydrates, Lipids, Nucleic-acids).
    - Cell organelles: with 34 questions (Prokaryotic and eukaryotic cell, Endoplasmic reticulum, Lysosomes, Nucleus, Mitochondria, Chloroplasts, Plasma membrane, Extracellular matrix, Golgi apparatus, Peroxisome, Cytoplasm).

2.4 Data analysis

For the analysis of student responses, the number of correct and incorrect responses was counted. Some questions accept more than one correct answer, others only one correct answer. Regarding the selection of checkboxes, there are four possibilities. To obtain a full grade, the student must tick only all the correct proposals. The student tick most but not all of the correct proposals, which leads to a lower score. If the student ticks some or all of the correct proposals with others that are incorrect, he will get an even lower score. Finally, the student tick only the incorrect proposals and thus obtains a negative or zero score. To get a score for each question, Egan suggested a formula (Egane, 1972):

$$\text{Egane score} = \frac{\text{The number of correct boxes chosen}}{\text{Total number of correct boxes}} - \frac{\text{The number of incorrect boxes chosen}}{\text{The number of incorrect boxes}}$$

According to this formula, a student's score range is -1 to +1. For example, in the case of a question with five proposals, suppose that an answer to the question requires

three boxes to be checked and that the student chooses two correct answers (out of the 3 expected correct ones) plus one incorrect answer (out of the two expected incorrect ones), so the score is given: 2/3 - 1/2 = 0.16. The Egane Score is used to calculate the rate of correct answers provided by students for each question. The more its value is equal to or close to -1, the more incorrect the answers are, and the closer the value is to +1, the more correct the answers.

3. Results

3.1 Results of responses to the questionnaire

More than half of the respondents (52%) say that they have already studied cell biology (cell, nucleus, chloroplast, mitochondria, etc.) in high school; and 48% say they studied it only in the first semester in university, which suggests that these students should have mastered the main concepts of cell biology.

A. The prokaryotic / Eukaryotic cell (Question 1)

In a prokaryotic cell, genetic material is free in the cytoplasm, which is surrounded by a plasma membrane. More than one of four respondents (46.25%) assert that the prokaryotic cell has a plasma membrane and a free DNA filament in the cytoplasm; while 65.62% of respondents say it has a nucleus delimited by a nuclear envelope. These results show that most students cannot understand the particularity of the prokaryotic cell. This can be explained by the fact that the students do not imagine a cell without a nucleus and they had studied only the model of the cell which has a well-defined nucleus, in their high school studies.

The eukaryotic cell contains a nucleus containing genetic material; it also has the specificity of containing organelles. More than one of seven respondents (76%) did not tick the right answers; while 24% of the respondents assert that the eukaryotic cell has a nucleus delimited by a nuclear envelope, and many organelles necessary for cellular metabolism. For this question, most of the respondents seem not to know that the cell contains organelles (eg: mitochondria, chloroplast…) that are necessary for cellular metabolism. This can be explained by the fact that the students think that the organelles are isolated from the cell.

B. The particularity of plant cells (Question 3)

The particularity of plant cells lies in having a skeletal (or pecto-cellulosic) wall. The majority of students (66.25%) answered this question correctly, however, 20% of the respondents gave incorrect answers and 13.75% of respondents could not answer this question (Figure 1). We expected that all participants would correctly answer this question since the notion of the plant cell was studied from the first year of college.

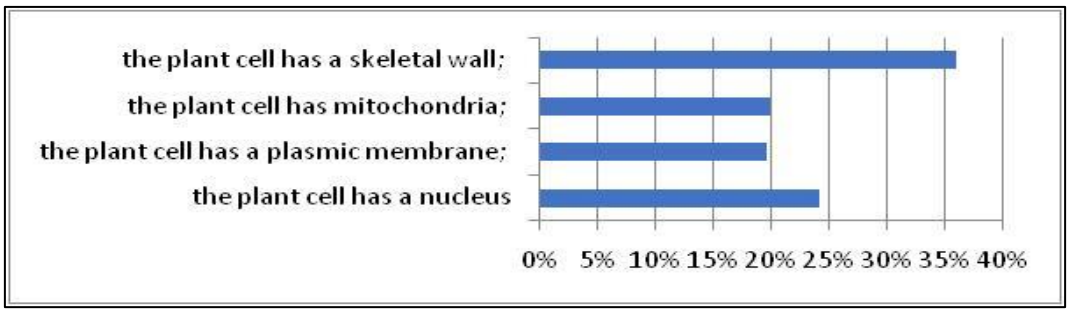

Figure 1: Student responses to Question 3 concerning the characteristics of the plant cell.DNA strand (Question 4)

Deoxyribonucleic acid or DNA is a biological macromolecule found in all cells; contains genetic information. DNA is made up of two complementary strands forming a double helix linked by hydrogen bonds. More than nine of ten respondents (92%) answered this question correctly, while 4% of students gave an incorrect answer and 4% could not answer this question. From these results, it can be said that the students understood that the DNA molecule is made up of two complementary strands.

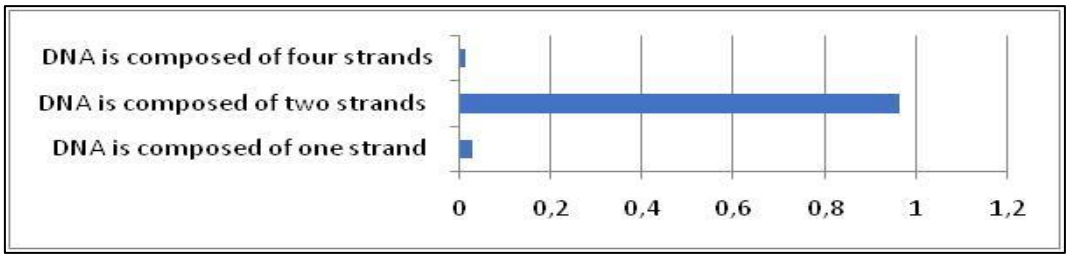

Figure 2: Student responses to Question 4 regarding the DNA strand

C. Proteins (Question 8)

A protein is a molecule made up of a chain of amino acids, an essential component of organic matter and living things. For this question, we see that 90% of the students answered correctly (Figure 3). This means that the students have a good understanding of the composition of proteins since they have studied them several times in their school courses (middle school and high school).

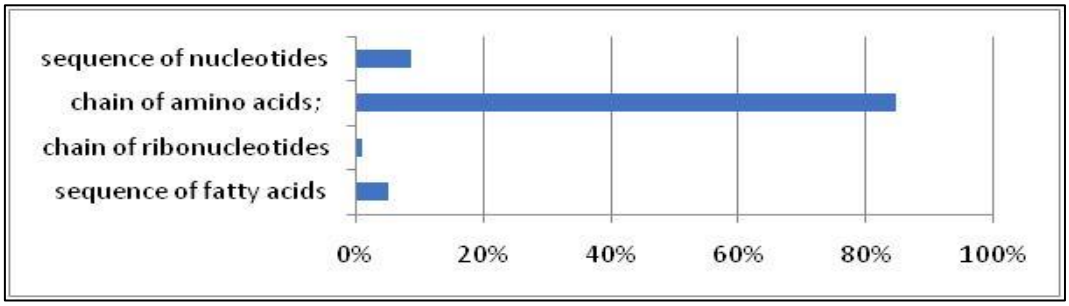

Figure 3: Student responses to Question 8 regarding protein composition

D. Amino acids (Question 9)

Amino acids are molecules that enter into the composition of proteins through their assembly by peptide bonds. Their name comes from the fact that they have an amine function (NH2) and a carboxylic acid function (COOH). They are distinguished by their side chain R. The percentage of correct answers (21%) is roughly equal to that of incorrect answers (25%); while 54% of students could not answer this question (Figure 4). This result shows that respondents have difficulty distinguishing amino acids, since only 21% of them report that amino acids are distinguished from each other by their side chain. This can be explained by the fact that the students did not fully understand the different chemical formulas of amino acids, and the different side chains.

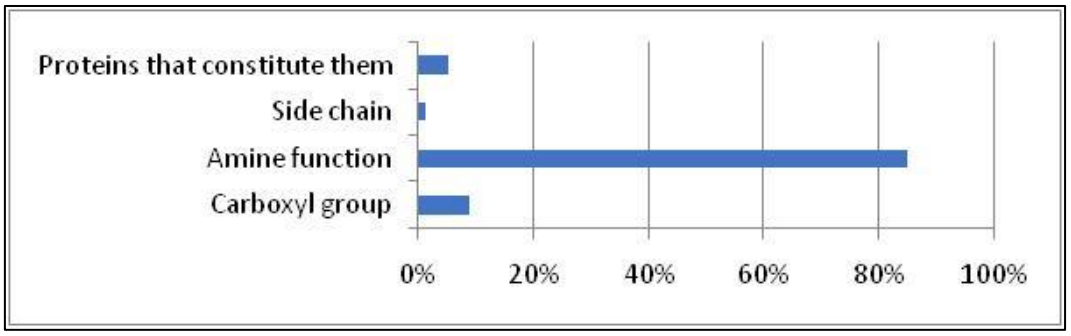

Figure 4: Student responses to Question 9 regarding the distinction between amino acids

E. The location of RNA in the cell (Question 10)

RNA (ribonucleic acid) is a biological molecule present in practically all living things, RNA is chemically very close to DNA and it is moreover generally synthesized in cells from a matrix of DNA of which it is a copy. RNA (mRNA) is localized first in the nucleus, and then in the cytoplasm, it is the intermediary between these two cell compartments. Only 48% of students answered this question correctly, while 13% gave incorrect answers and 51% did not answer (Figure 5). These results come from the fact that students have difficulty locating the different compartments of the cell and that the study of these items is done in isolation from the cell.

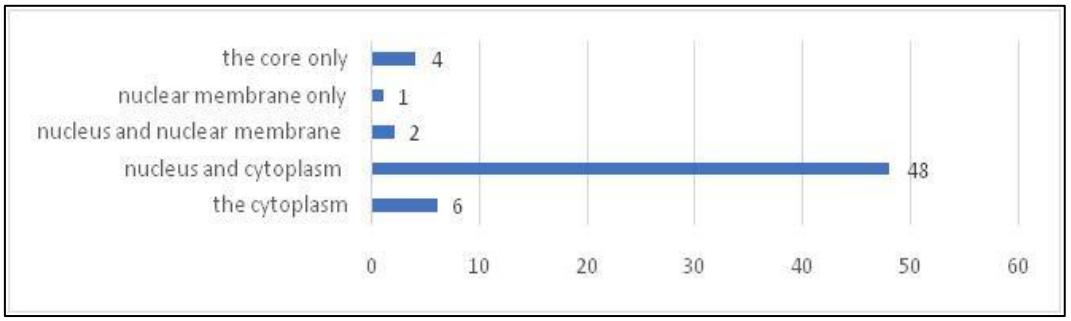

Figure 5: Student responses to Question 10 regarding the location of RNA in the cell

F. The transcription of DNA (Question 13)

One of four respondents (44%) asserts that transcription requires the intervention of RNA polymerase. RNA polymerase is an enzyme complex responsible for the synthesis of ribonucleic acid from a DNA template. Two of ten respondents (18%) gave incorrect answers and 38% could not answer. These results show that students have difficulty understanding the enzyme required for transcription.

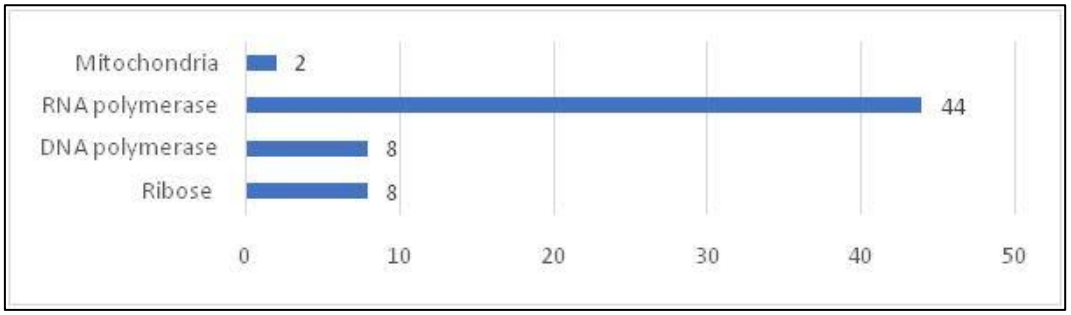

Figure 6: Students' responses to Question 13 regarding the intervention of the enzyme RNA polymerase during transcription

G. The rough endoplasmic reticulum (Question 14)

The rough endoplasmic reticulum is a system of more or less dilated cavities and canaliculi which communicate with each other, carrying ribosomes. It is in continuity with the nuclear envelope. Its role is the synthesis of intrinsic membrane proteins and proteins for extracellular use. One of four respondents (25%) stated that the endoplasmic reticulum is in a continuous relationship with the nuclear envelope, and it is the site of protein synthesis and ribosome maturation, while 66% of the students gave incorrect answers, 9% of participants could not answer. These results show that the students did not fully understand the structure and role of the endoplasmic reticulum.

H. The nucleus (Question 22)

The nucleus is a large structure surrounded by a double membrane; the nuclear envelope is continuous with the granular endoplasmic reticulum. The nucleus contains the nuclear genome, which is made up of DNA. DNA bound to Histones proteins takes two forms, more or less condensed (euchromatin and heterochromatin). Only 27% of the respondents gave a correct and complete answer and they could recognize the structure of the nucleus, while 54% gave an incomplete answer, 9% of the respondents gave an incorrect answer and 10% of participants could not answer this question. These results show that most of the students did not understand the structure of the cell nucleus well.

I. The origin of mitochondria (Question 23)

Mitochondria probably evolved from aerobic prokaryotic bacteria that were internalized by primitive eukaryotic cells. For this question, 32% of the respondents gave correct answers, while 16% gave an incorrect answer, and 52% could not answer (Figure 7). This result shows that students have difficulty knowing the origin of mitochondria, this can

be expressed by the fact that the history of the study of organelles is not taken into account during courses.

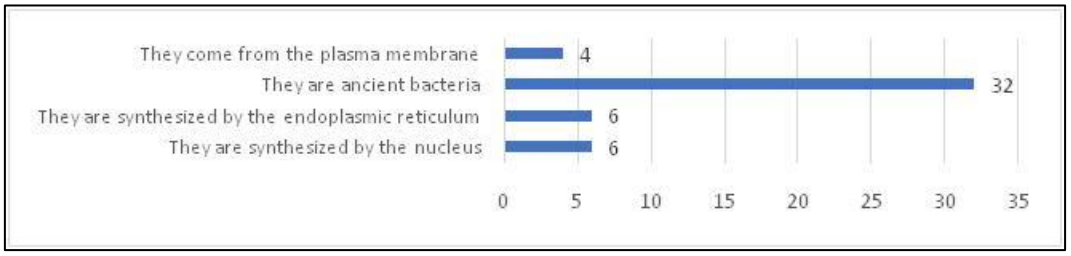

Figure7: Student responses to Question 23 regarding the origin of mitochondria

J. What do mitochondria synthesize? (Question 24)

Mitochondria essentially synthesize the ATP (adenosine tri-phosphate) molecule. The majority of respondents (83%) answered this question correctly, while 7% gave incorrect answers and 10% did not answer (Figure 8). This result can be explained by the fact that the students have already studied the notion of mitochondria at the level of the first and second year of the baccalaureate.

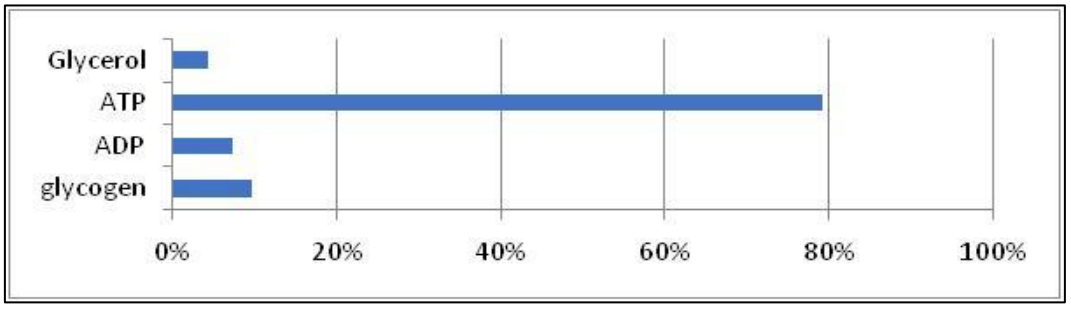

Figure 8: Student responses to Question 24 regarding mitochondria

K. Chloroplasts (Question 27)

The chloroplast is an organelle present in chlorophyll cells (plant cells), it is the place of photosynthesis, that is to say, the conversion of light energy into chemical energy in the form of organic molecules by reduction of CO2 and oxidation of water. More than one of three respondents (35%) gave a correct and complete answer, they were able to recognize the location of the chloroplasts and their functions, while 30% gave a semi-true answer, 10% gave incorrect answers and 25% of the students could not respond. These results show that most students have learning difficulties regarding chloroplasts (location, function), this can be explained by the fact that the students have not yet studied the course of plant physiology.

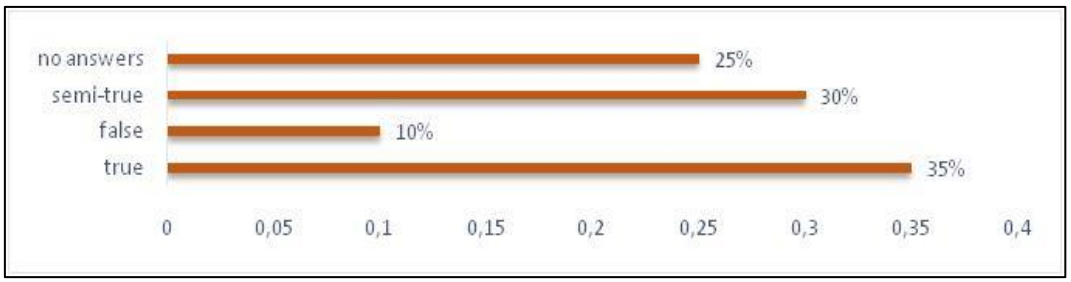

Figure 9: Students' responses to Question 27 regarding chloroplasts

L. The plasma membrane (Question 31)

The cell membrane is a thin structure that envelops a cell, separating the contents of the cell from its direct surroundings. It regulates the substances that can enter and leave the cell. For this question, the majority of students (86%) gave semi-true answers, while 10% gave wrong answers and 4% of students could not answer. There is a lack of correct and complete answers; this can be explained by the fact that students in a multi-choice question always have the impression that there are false propositions.

M. Peroxisomes (Question 34)

Peroxisomes are organelles unable to produce ATP, but they cooperate with mitochondria and chloroplasts to enable them to produce it. One in five respondents (49%) answered correctly, they could recognize the function of peroxisomes, while 15% gave incorrect answers and 36% of the students could not answer (Figure 10).

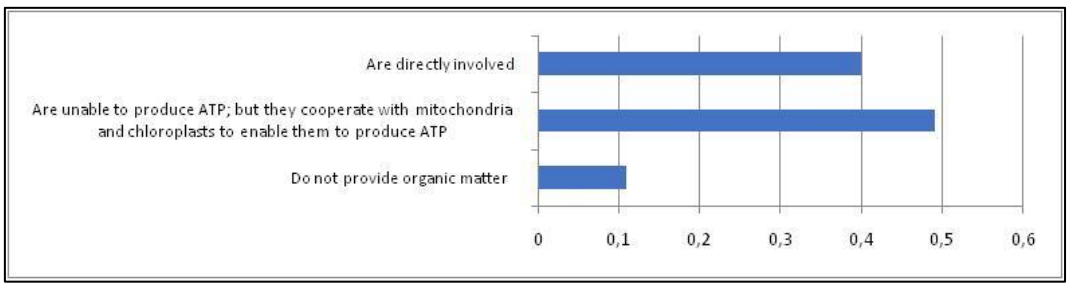

Figure10: Student responses to Question 34 concerning peroxisomes

N. Transport through the membrane (Question 41)

Through the cell membrane, the movement of molecules and ions between the intra-cellular and extra-cellular compartments takes place according to their properties and their chemical composition, in particular in lipids and proteins. Several types of transport intervene in this passage: simple and facilitated diffusion (passive transport), osmosis, and active transport. According to the results, almost half of the students (45%) did not answer this question and only 12% answered correctly and say that the entry of glucose due to the Na + / glucose transporter may be against the glucose concentration gradient, 20% say cells become plasmolysis in the hypertonic medium. On the other hand, 8% of the students said that the ions distribute themselves on both sides of the membrane in a random fashion and 15% answered that passive transport requires energy (Figure 11).

These results clearly show that the majority of students did not properly assimilate the concepts related to membrane transport despite these concepts already seen in high school.

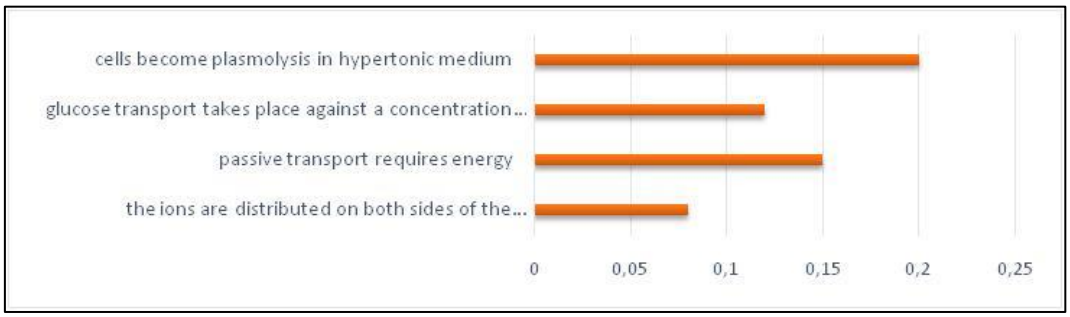

Figure 11: Student responses to Question 41 regarding transport across the plasma membrane

3.2 Results grouped by topic and calculation of the Egane score

The questionnaire is divided into two themes: organelles and chemical constituents.

- For organelles, we see that for most of the questions the Egane score points to -1, which confirms that the students have difficulty understanding this part of the cell biology module (Figure 12).

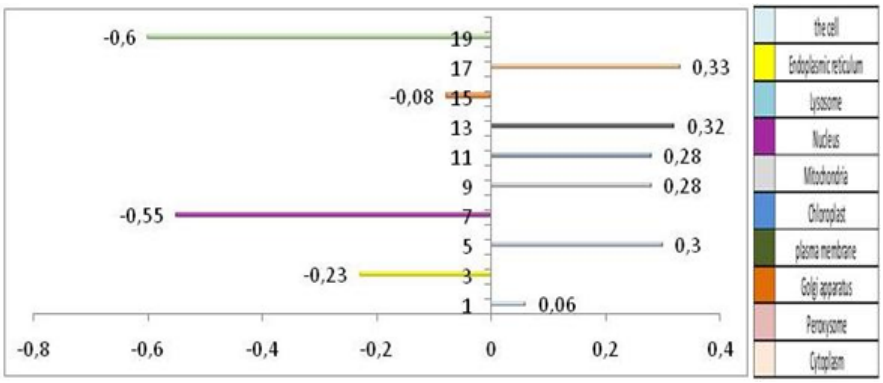

Figure 12: Student responses to questions about organelles

- For the chemical constituents, we notice that for all the questions the Egane score points to 1, which confirms that most of the students have assimilated the courses in this part of the module (Figure 13).

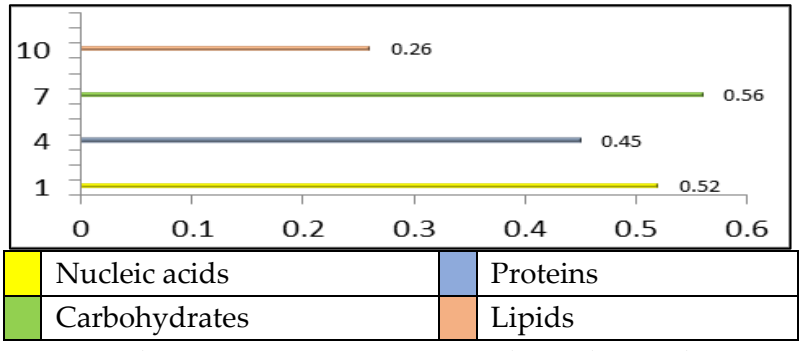

Figure 13: Student responses to questions about chemical constituents

3.3 Misconceptions identified among students

The results allow us to identify some misconceptions among the students as shown in Table 1. For example, "the prokaryotic cell contains a nucleus" which reveals the problem of representation-obstacle in learning in general and in university learning of cell biology in particular.

Table 1: Some misconceptions identified among students

The prokaryotic cell contains a nucleus
The eukaryotic cell contains only the nucleus without other organelles
Amino acids are indistinguishable from each other by their side chain
Mitochondria are nuclear or endoplasmic reticulum origin and not a bacterial one
Passive transport requires hydrolysis of ATP
Mitochondria are synthesized by Endoplasmic Reticulum
The cytoplasm is the liquid part of the cell which acts as a transport medium
The plasma membrane is coated with proteins
Plant cells are hexagonal and animal cells are spherical

4. Discussion and Conclusion

The cell biology course at the university is divided into two main parts: the chemical constituents of the cell and the cell organelles. Overall, the results show that the students seem to have difficulty understanding many concepts related to cell organelles and their functions. This is a common obstacle to confusing the cell with its peripheral double membrane (Clement, 2007).

Organelles are the different specialized structures contained in the cytoplasm and delimited from the rest of the cell by a phospholipid membrane (Golgi apparatus, endoplasmic reticulum… or double membrane (mitochondria, chloroplasts…). The students seem not to have well understood the function of these organelles; this may be because they are taught separately. On the other hand, students do not know the origin of certain organelles, for example, only 32% of students were able to recognize the bacterial origin of mitochondria.

On the other hand, students find difficulties in understanding cellular phenomena and processes in different levels of organization such as mitosis and meiosis, similar results revealed that students had misconceptions regarding the stages of meiosis (Degermana, M.S. & Tibell, 2012). Misconceptions had also been identified on the transport of proteins, the distribution of ions on either side of the cell membrane, diffusion, and osmosis, these misconceptions are revealed among students by many researchers (Odom, 1995; Garvin-Doxas et al., 2007). Likewise, we found that students present misconceptions about intracellular energy flow, these are consistent results with those of the study made by (Degermana, M.S. & Tibell, 2012). Both misconceptions about cell division as having already been shown in a previous study (Öztap, et al., 2003), which is one of the causes which make understanding notions relating to cell biology difficult, as has been specified in various studies (Bahar, et al., 1999; Marbach-Ad, & Stavy, 2000).

The other concepts of cell biology also seem to pose problems to the students such as the concept of the codon which means a triplet of nucleotides designated by the initials of the names of three respective bases, which determines the cellular synthesis of amino acids.

For the part concerning the chemical constituents of the cell, most of the students; although they find it difficult to classify the different amino acids according to their side chain; seem to assimilate the different chemical components of the cell, their properties, and, their function. This can be explained by the fact that they had already studied these concepts in secondary school. We find among the students some misconceptions, for example, the prokaryotic cell is a cell whose nucleus is delimited by a nuclear envelope, and it seems to be the eukaryotic cell. It turned out that the students have more difficulty understanding the structure of the nucleus and its functioning, these results are similar to those already proven by other research (Bahar, 2003).

It is also important to point out that several factors are at the origin of the misconceptions about the concepts of cell biology at the university, in particular the lack of learning resources that serve as a reference, the terms difficult to learn, as well as the strategy of teaching cellular concepts by teachers (Yusmina Hala et al., 2018; Dikmenli, 2010).

The causes of these difficulties can be due to several reasons; the language of instruction used is also an obstacle. The transition from the secondary level to the university level poses a lot of problems, students move from an Arabized system to a French system, which leads to a poor understanding of many concepts of Cell Biology although these concepts seem easy. Removing practical's work in the first year of university adds yet more problems. Indeed, practical's works are an opportunity to feel reality through the realization of microscopic observations. The traditional lecture is frequently a passive experience for students and teachers must use approaches that enhance their active participation in the learning process and that deepen their understanding (Bonwell, & Eison, 1991). Many notions including the structure of organisms will be better understood if the student sees them directly under an optical microscope or studies them through photomicrographs of electron microscopy observations. They also increase students' motivation to enjoy cell biology so that they can learn it better. This study has revealed that students appear to have some serious misconceptions about cell structure. Failure to identify a typical cell by several students indicates limited knowledge about the basic features of typical cells. There is also an apparent lack of knowledge and skill in identifying many organelles and their functions. From these results, it can be said that students failed to identify typical cells or to make a correct relationship between the structure and function of cells. Teachers need to be made aware of how to use methods that can help to address these misconceptions.

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Conflict of Interest Statement

The authors declare no conflicts of interest.

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