Students' conceptions of biological membrane models

Concepções de estudantes sobre modelos de membranas biológicas

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Abstract
The biological membrane is the central theme of this study. Frequently, the subjects about biological membranes are treated superficially and as simple cell structures. However, the membrane structure and its dynamic are complex and crucial to life existence. This study investigated the conceptions of undergraduate and graduate students about biological membranes and their knowledge about the models that evolved along the recent history of biological sciences. The results revealed that students describe only the Singer and Nicolson membrane model, which was published in 1972, but are unaware of the existence of other models of biological membranes. None of the students mentioned other than the fluid-mosaic model. Our results indicated that the conceptions of students about are associated with two core ideas, function and composition. We suggest that the biological membrane concepts should be taught in a non-mechanical way, including the critical and historical aspects that pushed the evolution of the models.

Keywords: Students' perception; Biochemistry; Teaching.

Resumo
A membrana biológica é o tema central deste estudo. Frequentemente, os assuntos relacionados às membranas são tratados superficialmente e como uma estrutura celular muito simples. No entanto, a estrutura da membrana e sua dinâmica são complexas e cruciais para a existência de vida. Este estudo investigou as concepções de alunos de graduação e pós-graduação sobre membranas biológicas e seus conhecimentos sobre os modelos que evoluíram ao longo da história recente das Ciências Biológicas. Os resultados revelaram que os alunos conhecem o modelo de membrana descrito por Singer e Nicolson, publicado em 1972, mas desconhecem a existência de outros modelos de membranas biológicas. Nenhum dos alunos mencionou outros modelos, apenas o modelo de mosaico fluido. Nossos resultados mostram que as concepções dos alunos estão relacionadas com duas ideias centrais, função e composição. Sugerimos que os conceitos de membrana biológica sejam ensinados de forma não mecânica, incluindo os aspectos críticos e históricos que impulsionaram a evolução dos modelos.

Palavras-chave: Percepções de estudantes; Bioquímica; Ensino.
1 Introduction

The Sciences that study life at the molecular and microscopic level are constantly evolving, making learning contents more complex, abstract and multi and interdisciplinary [1-3]. In view of the massive quantity of subjects that compose the curricula of elementary and high schools and universities, it is a great challenge for teachers to choose which set of knowledge are essential to generate quality learning [1]. Empirically, our experience and practices point out to a homogenous behavior of the teachers in opting to work superficially with a large quantity of complex contents. The main results for the majority of students is the construction of transitory and fragmentary mental models that will contribute very little to understand biology and other science subjects [4].

Our interpretation is in accordance with the results we obtained in a survey about undergraduate student’s perceptions about biochemistry [5], where most students had a negative view of the discipline or the teachers. The main complains about the teachers was the absence of concrete correlations between the topics covered in the biochemistry courses with the future professions of the students. Furthermore, the lack of abstraction skills essential subjects in chemistry and cell biology appeared also to have contributed to the negative views about biochemistry. In line with these interpretations, recent evaluations with pre-service biology teachers have indicated the importance of indeed reflections about methodologies used to taught complexes subjects such as molecular biology, particularly, in view of the difficulty of pre-service teacher in understanding abstract but critical concepts needed to grasp biology at the molecular and atomic level [6].

When referring to microscopic structures and molecular phenomena (which are not visualized with the naked eye) scientists and teachers have to generate models and visual representations, such as images, diagrams, graphs, among others [7]. The teaching of complex phenomena can also be facilitated by the use of analogies, metaphors and speeches [8-9]. These representations are commonly found in textbooks and ideally should be tools facilitated our understanding about physicochemical and biological processes [10]. However, the fragmented structure of complex contents about science presented to us during our entire school life does not allow us the proper assimilation and accommodation of meaningful and long-term models about basic physicochemical subjects required to understand biology at molecular level [11].

The currently accepted biological membrane model was described in 1972 – Singer and Nicolson [12], but before building and consolidate this model, many work and hypotheses were proposed by scientists. Pioneering experimental studies related to
biological membranes began to occur around the first three decades of the 20th century, where they were based on studies of lipid monolayers [13-15]. In this period approximately of half a century of studies, the biological membrane model evolved from lipid monolayer to lipid bilayer – Gorter and Grendel-1925 [15], sandwich model – Danielli and Davson-1935 [16] to mosaic-fluid model -Singer and Nicolson- 1972[12]. However, during the curricula of biological sciences or biochemical courses, the history of evolution of cell membrane concepts is superficially or frequently not covered.

In this research, we seek to investigate the spontaneous conceptions of undergraduate and graduate students about biological membranes, especially if students are aware of historical aspects about the conceptual evolution of biological membranes. Specifically, we also aimed to compare the concepts from graduate students enrolled in master or PhD courses in Biochemistry with science undergraduates students.

2 Material and Methods

2.1 Data collection

Data were collected at the end of the 2019 academic year and beginning of the 2020 academic year with the approval of students and teachers. Data were collected using a questionnaire containing 3 basic questions (see Table 1).

<table>
<thead>
<tr>
<th>Table 1: Questionnaire applied to undergraduate and graduate students at a Brazilian university</th>
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<tbody>
<tr>
<td>1. When we talk about biological membranes, what comes to your mind?</td>
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<tr>
<td>2. Draw how you imagine a biological membrane.</td>
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<tr>
<td>3. Do you know biological membrane model(s), explain.</td>
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</tbody>
</table>

To analyze the responses written by the students, we used textual discourse analysis [17] and the drawings were analyzed as described by Reiss and Tunnicliffe [18].

2.2 Sample

This research was carried out with 26 undergraduate and graduate students at a public university in Brazil. The characteristics of the sample are described in Table 2.
Based on the aforementioned methodologies, we analyzed the responses and images and separated them according to their similarities, which resulted in categories that will be described below.

3 Discussion and results

3.1 Students’ conceptions about biological membranes

The analysis of the answers given to the first question revealed two central ideas: function and composition. Table 3 shows this main ideas and the relationship with the ideas pointed out by the students, as well as the frequency of citations.

The following are examples that demonstrate each category that emerged from the analysis.

Regarding the **Function category**, 7 central ideas are listed:
• The biological membrane as a selective barrier function represented in the example “Selective barrier that controls the entry and exit of substances from the cells” (Graduate); “Selective layer formed by a lipid bilayer” (Undergraduate).

• The biological membrane as a function of delimiting the cells and organelles represented in the example “The first idea that comes to mind is that biological membranes have the primary function of involving and delimiting the space of specific components, such as cells or organelles” (Graduate); “A structure that surrounds other structures by involving them and separating them from the rest. For example, in a cell, a membrane acts as a layer to separate the contents from the rest, but still allows exchanges between the outside and inside” (Undergraduate).

• The biological membrane as a function of interaction between neighboring cells as shown in the example “Biological membranes are layers formed of phospholipids and proteins that line cells and organelles allowing or preventing the entry and exit of molecules, ions, as well as the interaction between neighboring cells” (Graduate).

• The biological membrane as a function of maintaining of life as shown in the example “These are phospholipid bilayer systems that enclosed environments that enables the sustainability of life and its processes” (Graduate).

• The biological membrane as a structure involved in the obtainment of energy: “They have a primary function in obtaining energy, such as the mitochondrial membrane and the complexes located in it (I, II, III and IV), in the electron transport chain” (Graduate).

• The biological membrane involved in the maintenance of the cell's work, for example “The membranes maintain the work that the cells need to do, allow the passage of substances, selecting what can or cannot enter the body” (Undergraduate).

• The biological membrane role in the immune process, as shown in the example “They act by hosting, linked to it, antigen (in the case of an antigen presenting cell), as well as antibodies that significantly contribute to the immune process” (Graduate).

In the Composition category, four central ideas were mentioned:

• The biological membrane is composed of Lipid Bilayer: “Lipid bilayer, formed mainly by phospholipids” (Graduate); “Lipid bilayer” (Undergraduate).

• The biological membrane is composed of proteins: “Biological membranes are layers formed of phospholipids and proteins” (Graduate); “They have channel, extrinsic or intrinsic proteins that allow the processes of large and small molecules from the
The biological membrane is composed of phospholipids: “The cell membrane is formed by a bilayer of phospholipids with polar heads (facing outward) and apolar tail (facing inward of the membrane) and transmembrane proteins that allow communication with other cells, entry and exit of substances” (Graduate).

- The biological membrane is composed of carbohydrates: “The membrane is formed by a lipid bilayer, cholesterol, proteins and carbohydrates (glycocalyx)” (Graduate).

It is noted that the most cited functions were selective barrier and boundary of the cells and organelles. This data shows that students did not express their ideas spontaneously, as they described concepts that we routinely find in didactic books used in undergraduate courses, such as for example,

The plasma membrane defines the periphery of the cell, separating its contents from the surroundings. It is composed of lipid and protein molecules that form a thin, tough, pliable, hydrophobic barrier around the cell. The membrane is a barrier to the free passage of inorganic ions and most other charged or polar compounds [19].

Although cited less frequently, we found more robust concepts, as shown by examples of functions related to maintenance of life, obtention of energy, and participating in immunological processes.

The difference in conceptions may be related the specific subject of research of student in postgraduate courses, which may not be directly related to cell membranes or that they have not realized that most phenomena related to life is connected to biological membranes at some point.

3.2 Representational levels of students’ conceptions of biological membranes

According to Reiss and Tunnicliffe [18], the only way for a researcher to understand a student's mental model about a certain phenomenon is through models expressed about this phenomenon. Therefore, we developed a system for evaluating the drawings, which corresponds to 3 levels, as shown in Table 4.

<table>
<thead>
<tr>
<th>Level</th>
<th>Description of concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Students consider that biological membranes are composed only of lipids.</td>
</tr>
<tr>
<td>Level 2</td>
<td>Students consider that biological membranes are composed of lipids and proteins, but do not explain the function of these components.</td>
</tr>
<tr>
<td>Level 3</td>
<td>Students show phospholipids, proteins and carbohydrates as composition of the membrane, in addition to mentioning the external and internal environment of the membrane.</td>
</tr>
</tbody>
</table>

We have also compared the answers collected in question 1 and the drawings in
question 2. The following are examples of the drawings made by the students and the respective answers given to question 1.

Level 1 represents a very simplistic biological membrane concept, as it is composed only of membrane lipids, two examples are shown in figure 1.

![Figure 1: Representation of the mental model level 1.](image)

**Cell membrane, lipid bilayer (Graduate).**

**They can be used to protect any system (Undergraduate).**

Level 2 is shown in the next figure. The figure shows some arrows indicating the composition of the membrane.

![Figure 2: Representation of the mental model level 2.](image)

**Generally a phospholipid bilayer, as a plasma membrane, mitochondrial, with proteins inside it responsible for the permeable character of this structure (Graduate).**

**Selective layer formed by a lipid bilayer, which have channel proteins, extrinsic or intrinsic that allow the processes of large and small molecules from the extracellular to the intracellular environment and vice versa (Undergraduate).**

Figure 3 shows examples of representations categorized at level 3. The students identified in more detail how they imagine a biological membrane, their representations are in accordance with the fluid mosaic model.
The data show that the level of conceptual representation has increased in some way with the level of education, shown in figures 1, 2 and 3. We highlight especially figure 3 which shows two examples of graduates, we have not found this level of representation in the drawings of graduation student.

However, we cannot affirm, since many graduate students made representations at all levels indicated in the discussion (see table 5).

It is noteworthy that many post-graduate students were doing research in the area of biochemistry, which involves processes that occur in the biological membranes, but have not expressed them in their responses and drawings.

Table 5. Conceptual representation and level of education.

<table>
<thead>
<tr>
<th>Levels</th>
<th>Undergraduate</th>
<th>Graduate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Level 2</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Level 3</td>
<td>---</td>
<td>5</td>
</tr>
</tbody>
</table>

3.3 Biological membrane models

Given the importance of the nature of the development of scientific knowledge [1], and the complete absence of biological membrane models in addition to the mosaic-fluid model by Singer and Nicolson [12], we seek to investigate how scientists came to the currently accepted definition of biological membrane.

All living organisms must necessarily have cells and for cells to exist, a membrane is needed to isolate them from the external environment and allow the maintenance of life [20]. The scientific knowledge related to the existence of the cell dates from the middle of the 17th century [21], however, in this article we focus on research carried out since the
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first decades of the 20th century, developed mainly by Langmuir [13], Gorter and Grendel [15], Danielli and Davson [16] and Singer and Nicolson [12].

Irving Langmuir [13], was interested in investigating the physical and chemical properties of solids and liquids. He tested different types of oils on water surfaces, described the properties of the molecules and concluded that unsaturated fatty acids occupy a larger water surface than saturated fatty acids. He also concluded that the film formed on the water surface has a deep molecule due to the chemical nature of the oil.

In 1925, Gorter and Grendel [15] investigated the composition of the cell membrane of animal cells (rabbit, goat, dog, guinea pig, sheep and human). They used blood cells (erythrocytes) because they are easy to isolate and extract lipids, as well as because they have no other organelles other than the plasma membrane itself. These researchers used the technique developed by Langmuir to measure the surface of lipids extracted from erythrocytes and concluded that the area occupied by the lipids is twice as large when compared to the area occupied by the intact cells, suggesting that there were enough lipids to form a layer with two thickness molecules, and therefore, a lipid bilayer.

The idea that biological membranes are composed of a fluid mosaic structure was proposed in 1935 by Danielli and Davson [16]. They discuss the expected permeability properties of very thin films and hypothesize that a layer of proteins is required to be present in any lipid in contact with the fluid content of the cell. They had the intention of showing that a pore structure had a relatively permanent existence in lipid films and that proteins would be able to show selective permeability for molecules of different sizes. The membrane model proposed by the authors became known as the sandwich model, in which it was suggested that the cell surface is composed of a thin film of lipids with a layer of proteins adsorbed on it on both sides, and that this film is able to distinguish between molecules of different sizes and characteristics of solubility and ions of different charges.

From a physiological perspective, it is essential to understand the structure that underlies dynamic systems, particularly through the composition of the cell membrane, which reflects a lot on the function of each type of cell [22].

Like Danielli and Davison, Singer and Nicolson also refer to the biological membrane as a fluid mosaic. However, they caution that generalizations should be avoided. In 1972, the authors published an article explaining the fluid mosaic model and emphasizing that to achieve a satisfactory understanding of how any biological system works, the molecular composition and structure of the system must be detailed. According to the authors, the biological membrane structure in fluid mosaic was the only model that followed the laws of thermodynamics. This model can be applied to most biological
membranes, such as plasma membrane, intracellular membranes, mitochondria and chloroplasts, however, there may be other similar systems such as the myelin sheath, and the membrane of some viruses that can be rigid instead of fluid.

Also in this model, Singer and Nicolson highlight the diversity in the composition, function and structure of the membrane's integral and peripheral proteins as well as the heterogeneous lipid composition. The authors criticize the classic model, in which the lipid bilayer would be sandwiched between two monolayers of proteins and argue that this model is not stable taking into account the laws of thermodynamics.

In a more recent update [23], the fluid mosaic model remains relevant to describe the basic nanoscale of biological membranes. However, information has been added that shows the importance of membrane domains, protein complexes, as well as the importance of cytoskeletal structures and extracellular matrix, which act in rapid and selectively responses to stimuli from outside and inside the cell.

Based on the literature review described above, we analyzed the responses given by students to question 3. Table 6 shows that 62% of respondents knew about the current mosaic-fluid model, 10% cited some didactic model, such as models made with recyclable materials, and 28% did not remember or cited other aspects related to the function of membranes.

<table>
<thead>
<tr>
<th>Membrane models</th>
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</thead>
<tbody>
<tr>
<td>Mosaic-fluid model</td>
<td>62%</td>
<td></td>
</tr>
<tr>
<td>Didactic model</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Not remember or cited other aspects</td>
<td>28%</td>
<td></td>
</tr>
</tbody>
</table>

Although consciously 28% of the students did not mention the fluid mosaic model, the representations expressed in the drawings show that 100% of the students were referring to this model.

4 Concluding remarks

We recognize that the conceptions and drawings presented here come from a restricted group of students, and generalizations should not be made. However, taking into account all aspects pointed out throughout the text, we conclude that basically the teaching of biological membranes has textbooks as the primary source of knowledge and we do not even think about the subjects we are presenting to students.

Thus, both the conceptions described by the students and the images drawn showed that they originated from mechanical learning-teaching classical approaches, preponderantly found in basic schools and universities. In fact, few students were able to
express knowledge in evolutive or functional terms (i.e., the importance of membranes as an initial step for evolution from a pre-biotic to a biotic chemistry or as an supramolecular structure to conserve energy). In general, we can interpret this as an indication that teachers and students are not in the habit of thinking more abstractly about atomic or molecular phenomena or structure (e.g. the biological membranes). Another outcome that we were expecting was to find a more comprehensive view about membranes from the part of the graduate students in relation to undergraduate students. However, this was not so evident possibly because our study had limitations, as we used open questions and the answers were superficial. Another limitation is that we do not conduct interviews with participants to find out what they meant by the respective drawings.

We suggest that when teachers work with concepts that seem simplistic for understanding, that the teachers themselves reflect deeply if they have already thought about their pedagogical praxis, if they have already thought about the biological membrane in a way that is not only mechanical, in biological, chemical and physical terms. Normally, the biology or biomedical teachers and students use to think membranes as a simple mechanical barrier, with some magical properties (transport, selectivity, etc); without connecting them to physicochemical properties of the membrane constituents. The physicochemistry of biological membranes is perceived superficially. In short, it is important to emphasize that that teachers and students should thrive to understand better basic aspects of membranes (including the structures and types interactions of lipids and proteins at atomic level), instead of privileging an enormous quantity of information that will be forgotten within a few months or even weeks after the end of a biochemistry course.

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