Models of immunity among college students: their evolution as a result of instruction[1]

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Abstract

The study of the evolution of the conceptual models of students is a topic of current importance in the didactics of science. Initial studies in the field of modeling were oriented toward describing the models of students and teachers and professors in different fields of knowledge with important results in didactics. Today, and particularly in this investigation, we assume the models as powerful representations to represent and build knowledge in the classroom. First we identified the college students' initial conceptual models of the concept of immunity. Then we applied a didactic unit aimed at the evolution of the initial models to immunology models determined by the curricular program in which the investigation was conducted. This qualitative research was conducted with twenty second-semester students of a university program in health sciences. Content analysis of the texts written by the students was carried out during an academic semester. The initial and final models of the students were characterized, as well as the change in the uses of languages and graphic representations, which are indicators of the understanding of molecular defense mechanisms that are part of innate and acquired immunity. It was observed that the models used by students before and after the educational intervention follow explanatory principles of the scientific models used in immunology.

Keywords

Models – Immunology – Teaching – Learning.

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Introduction

In the teaching and learning of science, representations play a central role. We can represent in our mind everything that surrounds us and we perceive with the senses; likewise, we can represent something that we imagine. From the perspective of cognitive science, representations are considered as any notion, sign or set of symbols that represent something of the outer world or of our inner world. In that sense they can be external or internal. The external ones are of public nature and produced largely by the (intentional or not) action of people; the internal ones are of individual character, *occupy a place* in the minds of the subjects, and allow us to look at the object in the total absence of its perceptible signifier; they can be concepts, notions, beliefs, fantasies, scripts, mental models, or images, among others (ORREGO; LÓPEZ; TAMAYO, 2013).

Given their important role in learning, representations are of special interest for both teachers/professors and students. A fundamental and common problem for different fields of knowledge is to know how subjects mentally represent their knowledge about the world, how they operate mentally with those representations, and how they can be constructed and reconstructed both in teaching contexts and in everyday environments. The use of our representations, along with mental models, is not confined to specific environments; we use them to solve any problem, be it in the educational, family or work environment. For Craik (1943), as a type of representation, models are structural, behavioral or functional analogs of real-world phenomena. Craik bases his hypothesis on the predictive capacity of thought and the ability of humans to explore the real world and imagine situations.

The pioneering studies on mental models from science didactics were oriented toward describing the models that students had in specific domains of knowledge, both the ones that referred to intuitive knowledge and to the knowledge acquired through instruction (TAMAYO; SANMARTÍ, 2007; VOSNIADOU; BREWER, 1992). At present, the basic orientation in the study of mental models is to understand what the process of construction and change is, what kinds of processes determine their use, and what the mental processes that allow their creation are, which implies recognizing them, knowing how they are represented in one's mind, how they are used by the subjects for their reasoning and how they are used by teachers/professors to achieve students' deep learning.

In addition to its descriptive intentionality, the use of models as a teaching and learning strategy is proposed, which has led to a fruitful line of research called model-based teaching and learning (GILBERT; BOULTER; ELMER, 2000; CLEMENT; REA RAMÍREZ, 2008; NERSESSIAN, 2008; GILBERT; JUSTI, 2016; TABER, 2013; JUSTI; GILBERT; FERREIRA, 2009). The central purpose of such line of research is to achieve student in-depth learning, to determine the validity of the expressed models, and to achieve better understandings of historical models in different fields of knowledge through instruction (GILBERT; BOULTER; ELMER, 2000). The study of models for these purposes is a strategy for the improvement of science education, because it is a starting point for the identification of the obstacles that students face to learn the concepts taught by teachers/professors.

In the study of the models in science didactics, both as representations and as epistemic artifacts, different meanings abound (GILBERT; JUSTI, 2016; KNUUTTILA, 2005b). Be they mediators (MORRISSON; MORGAN, 1999) or artifacts (KNUUTTILA, 2005a, 2011; NIA; DE VRIES, 2017), they are important in science education. According to Gilbert and Justi (2016), models function as external representations to support thought, and their construction and manipulation support several epistemic functions.

As epistemic artifacts, mental models not only inform about what subjects think, about how their thinking is constituted or how information is processed; they also provide useful knowledge about how models work in scientific practice in the classroom. In this sense, Knuuttila and Boon (2011) propose to consider modeling as a practice in which models become artifacts for the generation of new knowledge, which implies conceiving them as concrete objects, which are expressed with external representations and whose construction guides scientific reasoning depending on the type of representation; for example, images and charts allow types of reasoning different from those derived from linguistic or mathematical expressions. Considering models as epistemic artifacts leads us, on the one hand, to recognize models as concrete objects and, on the other, to recognize their role in the construction and reconstruction of conceptual models studied in classrooms.

By assuming the above, on the one hand, we present the characterization of the models used by health students to refer to immunological processes, in order to identify the main obstacles to learning this concept and, on the other hand, we consider students' explanatory models as mediators in the process of knowledge construction, which requires teachers' conscious and intentional actions to design teaching environments that promote change in the conceptual models of students (LUKIN, 2013). In other words, the characterization of models and obstacles becomes the guiding principle for the actions of biology teachers. The study presents the characterization of the changes in the explanatory models employed by the students, which we assume from an evolutionary perspective (TAMAYO; SANMARTÍ, 2007; TAMAYO, 2009).

Immunity models

Immunology is a modern science that has developed hand in hand with microbiology. It is a biological science that studies physiological defense mechanisms; these mechanisms consist essentially of the identification of the foreign and its destruction. The immune response is considered the integrated action of a large number of defense mechanisms against foreign substances and agents. Foreign substances are called antigens and they are the ones that trigger in the organism a series of cellular events that provoke the production of defense mechanisms. Immunity began to be defined through experiences and intuitive observations about 500 years BC. Different models that explain defense mechanisms have been proposed in the history of immunology. Among these models are: the supernatural, the imbalance, the miasmatic theory, the astrophysics, and the classical model of immunity, and the pre-scientific and scientific models of immunity (BERRÓN PÉREZ et al., 2003; DOSNE, 2009; IGLESIAS GAMARRA et al., 2009; MAZANA, 2003;

SILVERSTEIN, 2009; VARELA, 1997). Next, in Chart 1, we present the models that have been historically constructed to explain immunity.

Char 1- Main models of immunity constructed throughout the history of biology

Main models of immunity throughout history
Supernatural model: Diseases caused by supernatural forces. Illness as a form of theurgic punishment by gods or enemies, for bad acts or evil thoughts that visited the soul.
Imbalance model: Diseases attributed to an alteration or imbalance in one of the four humors: blood, phlegm, yellow bile, and black bile. Use of therapies such as bleeding, suckers, leeches, and purgatives, as well as expectorants of many types (Hippocrates).
Model of the miasmatic theory: Diseases caused by a miasm, a harmful form of choking air. Exposure to miasm generates disease. Whoever recovers from the disease has a balsamic blood, which makes him or her safe from this disease in the future (Paracelso, Girolamo Fracastoro, Thomas Sydenham).
Classical or biological model: Immune system as a military system. The body responds to external threats by attacking or combating foreign agents.
Pre-scientific model: You do not suffer an infectious disease twice and suffering the relapse of an infectious disease is never fatal. Tucídides (465-395 B.C). *Theory acquired immunity*: Exposure to pathogens confers lasting immunity. Al-Razí (X century). *Mithridatism*: Resistance to toxins: the organism becomes resistant to the action of a certain toxin by its successive intake in small doses (132 B.C. y 63 B.C.). Immunity is acquired by variolization, scarification (macerated crusts) or gradual ingestion of toxins. Emergence of the immunity acquired in an active natural and artificial way.
Scientific model: Core concepts: prevention, immunization, etiological agent, resistance to disease by vaccination, active immunity, cellular immunity, phagocytosis, complement, inflammation, humoral immunity, antibody, immunochemistry, clonal selection theory, idiotypic network, natural immunity, age immunity, species immunity, racial immunity, natural barriers, among many others.

Source: Taken and adapted from Iglesias Gamarra et al. (2009) and Silverstein (2009).

From the perspective of the teaching and learning of sciences, we highlight the studies of Maguregi, Uskola and Burgos (2017), who, based on vaccination, teach aspects related to the immune system. The works of Aznar and Puig (2016a, 2016b) on conceptions and models of primary teacher candidates about tuberculosis also stand out. In general, the research results show that the ideas expressed by the students are very far from reference scientific models. Lundström, Ekborg and Ideland (2012) analyzed the development of argumentation and decision-making in adolescents through teaching focused on scientific controversies about vaccination or no vaccination against influenza. De Andrade, Araújo Jorge and Coutinho Silva (2016) found that most students attributed to the immune system attack and defense actions aimed at protecting the organism against the invasion of pathogens and foreign bodies; these authors, like Aznar and Puig (2016a, 2016b), report limited knowledge about the dynamics of interactions of the organism with itself and with the elements of the environment.

The study of the students' conceptual models of immunology and their change as a result of instruction are the central objectives of this research. Below we present its methodological aspects.

Methodology

This qualitative study describes the conceptual immunity models of twenty college students of the second semester of a health program, of a Colombian university, taking the Cellular and Molecular Biology discipline. Information was collected with an open-response questionnaire with daily situations related to different immunological processes (see Table 2). In addition, we used a Likert-type instrument with ten items with justification of the answer. In addition, students were asked to graphically represent various immunological processes (see Chart 2). This information was collected over eighteen weeks, the length of time of the application of the didactic unit by one of the researchers. Before doing the corresponding analyses, we triangulated the information obtained with the instruments described above. First, the didactic unit presents a questionnaire to explore previous ideas on immunity. It also contains the objectives and the development of all the conceptual, metacognitive, language use, and argumentation activities. The topics taught in the didactic unit were: bacterial structure and metabolism; structure and reproductive cycle of viruses; natural immunity and adaptive immunity.

Chart 2- Typology of questions proposed to students. CA: Completely Agree, A: Agree, D: Disagree, CD: Completely Disagree

Typology of questions* proposed to students
Question 1: 1. Students of health colleges are required to receive a certificate of hepatitis B vaccination upon admission. Can you explain why? Question 3: When we are hit, the affected area swells. Can you explain why? Question 9: A child who fell off a bicycle and hit his face comes to a medical consultation. The child has redness, pain, swelling, and increased temperature. How would the doctor explain this phenomenon to the child's parents? Question 12: One is more likely to be allergic in childhood than in adulthood. CA ______ A________ D________ CD________ Justify your answer. Question 13: When a mosquito bites us, our skin swells, becomes red, and our temperature increases. CA ______ A________ D________ CD________ Justify your answer.

* The questionnaire consisted of 10 open questions and 10 Likert-type questions, of which 5 are presented, in order to illustrate the type of questions used.
Source: The authors.

The teaching process consisted of the following steps: a) administering a questionnaire to explore students' initial explanatory models of immunity; b) identifying possible obstacles to learning the concepts of immunity taught; c) planning teaching activities that included conceptual, metacognitive, argumentative, and scientific language use aspects; d) conducting the teaching process – It should be noted that throughout the classroom experience the aforementioned instruments were applied to collect information –; e) once the teaching activity was completed, we applied the questionnaire again to explore the students' final explanatory models.

After collecting information with different instruments previously validated by experts, we identified the core sentences (CHOMSKY, 2004) of students in the field of immunology. The Atlas-Ti software was used for the central and axial categorization process. All the responsess given by the students to the different questions before the educational intervention were characterized and then expressed in percentages according to the conceptual models of immunity to which they referred (classical, pre-scientific and scientific models). Then we developed semantic networks that describe the most characteristic aspects of the conceptual models of immunity. With the information yielded by the different instruments applied throughout the teaching activity, we characterized the evolution of the conceptual models of the students.

Immunity before the educational intervention

Before the educational intervention, we identified three conceptual models: pre-scientific, classical and scientific (see Table 3). The pre-scientific model is related to the immune system, acquired resistance and the postulate of Thucydides; the classical model is related to the immune system as a system that attacks or fights the foreign. 90.4% of the core sentences (CHOMSKY, 2004) written by the students were located in the scientific model, that is, 549 of a total of 607 sentences analyzed. In this model, the defense, innate immunity, acquired resistance, transmission, and vaccination categories are highlighted (see Table 1).

Table 1- Percentage of responses about the immunity model Prior to Educational Intervention (PEI) and percentage of responses found for the PEI scientific model

Inmunity models (PEI)		Scientific model of immunity (PEI)	
Model	**Percentage of responses**	**Category**	**Percentage of responses**
Pre-scientific Model	3.4	Defense	14.2
		Innate immunity	23.1
Classical Model	6.1	Immune system	1.8
		Acquired resistance	15
Scientific Model	90.4	Transmission	12.2
		Vaccination	22.9

Source: The authors.

Next, in Table 2, we present some of the most frequent responses in the conceptual models of the students.

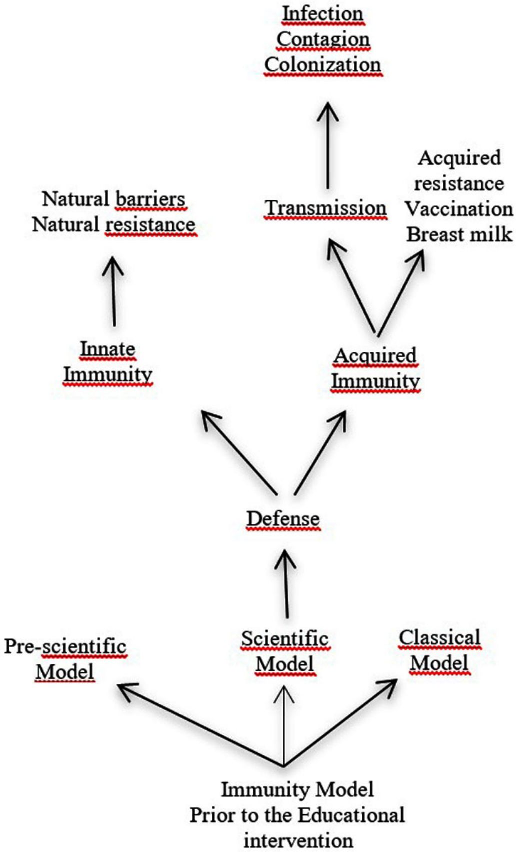
Table 2- Typology of responses given by students to explain phenomena related to immunity

Question*	Response
5. In the environment that surrounds us, there are many microorganisms such as: bacteria, viruses, fungi, and parasites. These microorganisms colonize many people but only some develop the disease. Can you explain why?	5.9. Some people develop this disease... because they may have low defenses. 5.16. ... because their defenses are low or because the environment that surrounds them makes these microorganisms attack them and makes them be exposed to diseases. 5.20. Because of the defenses, if they have many or very few defenses they can develop the disease; it also depends on food, medical check-ups, and general health care. 5.27. I think some people do not develop the disease because they have good defenses that help counteract microorganisms.
7. Plasmodium vivax does not cause malaria in 80% of blacks, while most whites are infected by this parasite. How could this phenomenon be explained?	7.17. In comparison to black people, white people are very likely to suffer more diseases. 7.19. Because black people have a mechanism that defends them against that. 7.21. Perhaps white people are more likely to get this virus, black people may be stronger at this because of their skin type.
15. Babies fed on breast milk are more resistant to diseases caused by microorganisms CA A D CD because:	15.33. A, because breast milk has components with high defenses for the child and that are also very important for the correct and good development of the baby. 15.25. CA breast milk not only provides carbohydrates and proteins, but also provides defenses to fight many microorganisms. The child comes into contact with different microorganisms from both the mother and the environment. 15.14. CA breast milk has more vitamins, more defense substances for the baby, which cow's milk does not have, and this milk is processed. 15.8. A, through the mother's milk, they acquire the defenses of the mother.

* We present three (3) questions (5, 7 and 15) to exemplify some of the responses given by the students.
Typology of responses given by students to explain phenomena related to immunity.
CA: Completely agree, A: Agree, D: Disagree, CD: Completely disagree.
Source: The authors.

Students refer to the term *defenses* to express that they may be well or poorly developed in an individual or may be low, which may favor the development of microorganisms. In general, they simply talk about defenses without explaining their mechanisms of action. As shown in Figure 1, the category defense is directly related to the presence or absence of disease. In their responses (see Table 4), students fail to explain the function of the adaptive response (acquired immunity), whose purpose is to activate defense mechanisms against aggressive microorganisms. The students mention that breast milk transmits defenses to babies, and relate the nutrients of breast milk to acquired resistance, without making scientific explanations of what happened.

Figure 1- Representation of students' immunity model – inferred from their responses – before the educational intervention. Although there is a marked tendency to refer to the conceptual model of immunity, as it was clear in Chart 1, students also refer to pre-scientific and classical models.



Source: The authors.

Likewise, they state that many individuals present (natural) resistance to some diseases caused by pathogens, because it is the type of resistance conferred by the constitutive factors of innate immunity, resistance related to race, species and genetic immunities (see Figure 1). Students have the concept of natural resistance associated with species immunity, although they do not refer explicitly to the latter or identify this type of immunity as part of natural immunity. In addition, they mention the concept of racial immunity based on the concepts of resistance and susceptibility. In general, one can say that the students do not know the immunological processes that occur in the organism, the terms to refer to passive and active acquired immunity, or to the molecular processes that they explain. The answers are simple and general and fail to make reference to the processes that allow acquiring immunity in a natural or artificial way. We emphasize that there is a lack of knowledge of the etiological agents of infectious diseases. We also emphasize that they do not know the molecular mechanisms through which a microorganism enters the host cells. Although they mention some terms such as acquired immunity, race, specificity, ability to remember, the students do not give molecular explanations on how the cells of the immune system recognize the microorganisms; in short, they are not aware of the molecular and physiological events that occur in specific defense mechanisms, such as cellular immunity and humoral immunity.

Immunity after the educational intervention

In Table 3 we present typologies of responses given by the students after the educational intervention. We identified two conceptual models: the classical and the scientific ones (see Table 4). The classical model is related to the immune system as a system that attacks or fights the foreign. In the scientific model were located 98% of the core sentences (CHOMSKY, 2004) made by the students, that is, 719 of a total of 734 sentences analyzed. It is noteworthy that all 719 core sentences refer to elements of scientific nature. In other words, and according to Chi (2008), they are statements that pertain to the same ontology; however, the uses of language, the reasoning processes employed, and the concepts to which they refer are of low complexity.

This model highlights the categories: *innate immunity*, within which students refer to species, race, and age immunity, as well as to receptors; and *acquired immunity*, within which students refer to passive or natural immunity, immunological memory, disease, and vaccination. The responses classified in this model correspond to the theoretical approaches that are part of the immune system specifically on natural immunity and acquired immunity.

Table 3- Typology of responses given by students to explain phenomena related to immunity

Question	Response
7. Plasmodium vivax does not cause malaria in 80% of blacks, while most whites are infected by this parasite. How could this phenomenon be explained?	7.14 It can be explained by innate immunity, within which there is a very important constitutive factor, which is the immunity of race, which applies in this case, since black people do not have the Duffy receptor and white people have the Duffy receptor on the erythrocyte membrane (red blood cells), which allows the recognition of the virus and its subsequent colonization.
14. Children who suffer from chickenpox when they are adults never again have this disease CA A D CD Because:	14.14 CA, I fully agree because when suffering from the disease our immune system lies in the ability to recognize the type of microorganism that produced such disease to remove it later; this is called “acquired immunity”. 14.15 CA, The immune system, more specifically the cells of acquired immunity, developed memory against the microorganism causing varicella when they suffered from the disease.
17. People who develop AIDS die from cancer or from infections caused by different types of microorganisms, such as those that produce tuberculosis, hepatitis, or pneumonia. CA A D CD Because:	17.12 CA, AIDS is a disease caused by HIV; this virus acts on the cells of the immune system which causes them to be affected and unable to fight certain dangerous microorganisms, which makes the body very vulnerable. 17.16 A, The HIV virus attacks T lymphocytes and these are the ones that activate B-lymphocytes. Then the absence of these cells makes the immune system weak and unable to easily attack the microorganisms that adhere to the tissue. 17.18 CA, Because people with the HIV virus have a major deficiency in their immune system and this causes different organisms that cause any type of disease to enter the affected body and affect it with great ease until death.
19. Americans and Europeans travelling to tropical areas are required to take the vaccine against malaria. CA A D CD Because:	19.16 CA, Because Americans and Europeans are white people and, therefore, their erythrocytes contain the Duffy receptor, which recognizes plasmodium vivax, and the latter is the cause of malaria. 19.1 A, In the tropics, it is common to find plasmodium vivax, responsible for transmitting malaria and more so as the people of these places tend to be white, they do not have the Duffy receptor on the membrane of their cells.

Typology of responses given by students to explain phenomena related to immunity.
CA: Completely Agree, A: Agree, D: Disagree, CD: Completely Disagree.
Source: The authors.

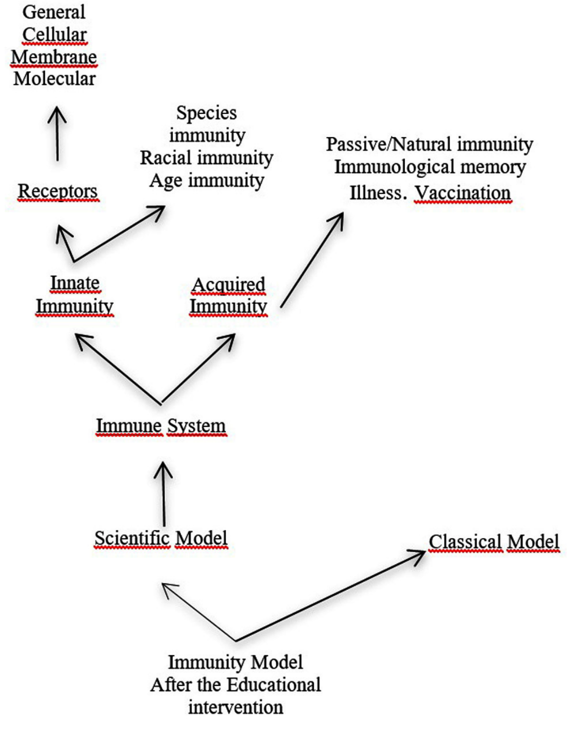
Table 4- Percentage of responses for the immunity model After the Educational Intervention (AEI) and percentages of answers found for the scientific model AEI

Immunity models (AEI)		Scientific model of immunity (AEI)	
Model	**Percentage of responses**	**Category**	**Percentage of responses**
Pre-scientific	0	Innate immunity	48.8
		• Species	3.8
Classical	2.0	• Race	5.3
		• Age	0.7
Scientific	98.0	• Receptors	29.4
		Acquired immunity (Passive / Natural immunity, Immunological memory, disease, vaccination).	35.1

Source: The authors.

Students relate innate immunity with racial immunity, species immunity, genetic factors, and natural barriers. When we ask questions to inquire about the constitutive elements of innate or natural immunity, we find that, after the educational intervention, the students recognize the components of this type of immunity, with explanations at the cellular and molecular levels; 48.8% of the responses given by the students (358 responses out of a total of 734) refer to the category of natural immunity, within which they refer to immunity of species, race and genetic factors. Students identify the receptors to explain host cell-microorganism interaction or immune cell-microorganism interaction. To refer to the receptors, we find general responses from students in which no cell structures are specified. Some students do so generally without placing them in cellular or plasma structures; others place the receptors in the cell without specifying their location, and others place them specifically on the membranes (see Figure 2). They also have the concept of acquired immunity. They identify the types of active, passive immunity and they recognize that this type of immunity is acquired naturally or artificially, 35.1% of the responses given by the students (258 out of 734) refer to this type of immunity (see Table 6). Students explain that active acquired immunity is generated when one has suffered from an infectious disease caused by microorganisms, or by processes of vaccination. In addition, they mention that when one acquires this type of immunity, immunological memory is generated for a later recognition of the antigens.

Figure 2- Immunity model after educational intervention. The scientific model is conceptualized from the concept of defense, from which the concepts of innate immunity and acquired immunity derive



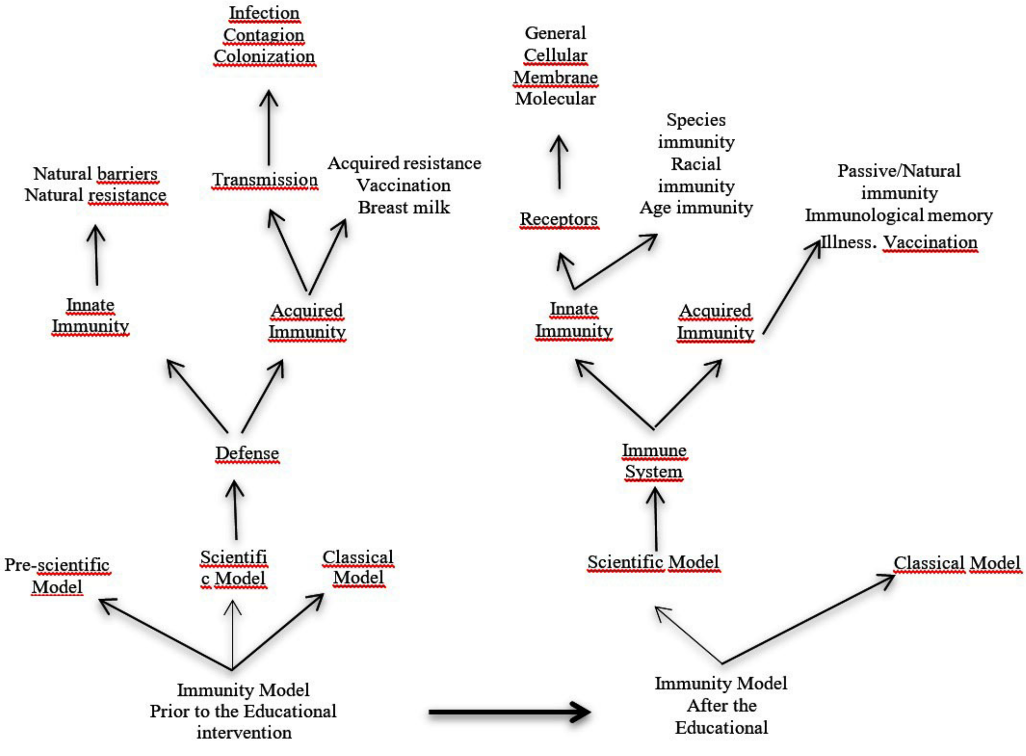
Source: The authors.

Students make explanations of receptors as molecules for the recognition of antigens, for example, viruses or bacteria. They recognize microorganisms as etiological agents or pathogens, differentiate between etiological agents and infectious diseases, for example, describe AIDS as an infectious disease caused by the HIV virus. In addition, they are able not only to explain that this virus infects cells of the immune system but also to describe the functions of different types of lymphocytes. They use specialized language that demonstrates that they understand the general and molecular processes that explain phenomena related to immunology (see Table 4). In Figure 2, we represent the model of immunity of the students after the educational intervention, inferred from the responses given by them. The central concepts associated with the scientific model are highlighted in this model of immunity: Immune system, acquired immunity and innate immunity, with corresponding components (see Figure 2).

Among the main differences found between the models prior to and after the educational intervention (see Figure 3), we can point out the following:

- Regarding the structure of the concept of immunity. Before the educational intervention, the model of immunity found in the students was constituted by the pre-scientific, classical and scientific models. With a total of 90.4% of the responses, the scientific model is structured on the basis of the concept of defense, from which the concepts of natural and acquired immunity derive. In turn, acquired immunity is structured from the concepts of transmission, acquired resistance and vaccination. On the other hand, after the educational intervention, the model of immunity was conformed by two models: the classical one and the scientific one. The scientific model of immunity, with 98% of the responses, was structured from the category immune system. The scientific model was structured from the category immune system, constituted in turn by the categories acquired and innate immunity (see Figure 2). It seems clear that the structure of the immunity model, after the educational intervention, is more precise in terms of its logical structure and the use of specialized language.
- The core category that catches the attention of students before the educational intervention is *defense*. After the intervention, the core category is *immune system*.
- After the educational intervention, there was greater specificity than that achieved before the intervention (see Figures 1 and 2).

Figure 3- Comparison of immunology models prior to and after the educational intervention (left and right respectively)



Source: The authors.

Discussion

The results described in previous pages lead us to discuss five aspects of student learning: (a) value of previous ideas in the learning of immunology; (b) compatibility between everyday knowledge and scientific knowledge in the field of immunology; (c) learning within ontological categories; (d) evolutionary perspective for the learning of immunology; and e) teaching directed to the evolution of the conceptual models of the students, in which the models are considered artifacts of knowledge. We shall now discuss the aforementioned aspects.

Value of previous ideas in the learning of immunology. Recognition of previous ideas as a point of departure for teaching has been a central principle of good teaching. In the context of university education, and particularly in relation to the learning of immunology, students' previous ideas seem not to have much impact. The knowledge that college students have about immunology seems to be little influenced by everyday knowledge, by virtue of two essential aspects: its nature and its depth. On the one hand, the everyday knowledge that students have about immunology, before entering university, is so general and superficial that it has little effect on the learning of the scientific concepts taught. On the other hand, the great conceptual development achieved in this field, with the participation of anatomy, molecular biology, biochemistry, and biophysics, among other sciences, makes this a highly complex field that requires a scientific approach to be learned. In other words, the previous knowledge about immunology that students have upon entering university does not appear to be an obstacle to new learning.

Compatibility between everyday knowledge and scientific knowledge in the field of immunology. We can affirm that the learning of immunology in the context of university education follows the hypothesis of the compatibility between everyday knowledge and scientific knowledge (TAMAYO, 2009). Since the previous ideas with which students enter the university classrooms are of the same nature as the scientific ideas taught by the professors, the learning of the models taught mainly follows the path of gradual enrichment of what the student already brings to the classroom. In other words, the learning of the models of immunology basically follows a process of differentiation and categorization of the principles of the scientific model with which the students enter the program. Note that the percentage of responses pertaining to the scientific model before and after the educational intervention was 90.4% and 98%, respectively. In this sense, the teaching action is basically oriented to making adjustments in the existing categorization process, recognizing complementary categories, using language appropriately, relating new learned categories to existing ones, and obtaining more complex explanations of the different phenomena studied. In short, student learning occurs mainly due to the gradual enrichment, at the conceptual and language levels, of the model with which s/he enters the classroom.

Learning within ontological categories. Given the characteristics of the concepts in immunology, and according to Chi (2008), for their learning, students follow processes of weak conceptual change, characterized by learning within the same ontological category. As we described in the analysis of the information, students do not enter the science classroom in the university with previous knowledge about immunology of an ontological nature different from that of scientific knowledge. In other words, they do not require, in this case, radical conceptual changes in which concepts are reallocated to different ontological categories. Consequently, their teaching is anchored to the scientific model of immunology, emphasizing the complete ontology of the latter.

Evolutionary perspective in the learning of immunology. We consider that the evolution of the learning of explanatory models in immunology is characterized by two aspects. The first one is the gradual complexity of the explanations. Consistent with the above, the process of learning immunology follows a gradual dynamic of enrichment which builds on the prior knowledge that students bring to the classroom. The development of explanations with different degrees of complexity, characterized by a greater number of variables and different types of causal relationships between them, allows considering this learning perspective an evolutionary process. The second one is the improvement in the uses of the language. Linked to the gradual conceptual requirement in the learning of immunology is the adequate use of terminology in this field of knowledge. The gradual, conscious and intentional incorporation of specialized language for the purpose of explaining phenomena related to immunology is an indicator of student learning.

Teaching directed at the evolution of student models. The action of professors improves through the incorporation of model-based teaching and learning (GILBERT; BOULTER; ELMER, 2000; CLEMENT; REA RAMÍREZ, 2008; NERSESSIAN, 2008). The central purposes of this teaching perspective are, among others, to achieve in-depth student learning (GILBERT; BOULTER; ELMER, 2000; SAWYER, 2006; RAMÍREZ; TAMAYO, 2011), to determine the validity of the models expressed, and to achieve better understandings of the models that have been historically constructed in the different fields of knowledge and their teaching (GILBERT; BOULTER; ELMER, 2000). Research from the perspective of models in science education is considered from at least two perspectives: the conceptual models of the students, the first and most studied; and the second is mental models. These two perspectives of work have as main distinctive aspect their restriction or not to elements of conceptual nature. In this regard, it seems pertinent to limit the use of the term conceptual model to models of an explanatory nature (for example, chemical bond, cell and immunity models) and to limit the use of the term mental model to the models in which aspects of conceptual, cognitive-linguistic and motivational nature are integrated.[4] A teaching process oriented to the evolution of conceptual models focuses its attention on the logical structure of the concept taught, on its hierarchical and relational organization of the different concepts that constitute it. A teaching process oriented to the evolution of mental models allows to carry out actions in order to gradually achieve more integral explanations of the processes studied, explanations that incorporate metacognitive and motivational aspects of conceptual nature, of uses of language.

In the particular case of the teaching of immunology, we do not find among the students different conceptual models of the phenomena studied, as Legare and Gelman (2008), for example, point out when referring to natural and supernatural explanations of the disease. In the terms of Giere (1992), we cannot refer to a family of models in immunology. Instead, we find that students explain immunological phenomena almost exclusively from elements of the scientific model. In this sense, the conceptual evolution of the students showed weak changes (CAREY, 1992; SPELKE, 1991), occurred within the scientific model, mainly related to greater precision in the use of existing ideas, by the incorporation of new ones, by the use of specialized language and by explanations at the molecular level. These weak changes are due to processes of modification of the initial conceptual model with which students enter the classroom, which is possible when the initial model is partially compatible with the model taught (NÚÑEZ OVIEDO; CLEMENT; REA RAMÍREZ, 2008). In this way the evolution of the model can occur by the addition, elimination or rethinking of one or some of the elements of the starting model. From this perspective, a stepped strategy is assumed in the evolution of the models whereby students restructure their initial models to produce successive intermediate models, until reaching the arrival model proposed for the class.

4- This differentiation seems important insofar as the tradition of research on models in science didactics calls *mental model* specifically the models of a conceptual or explanatory nature of a particular concept or phenomenon.

Final remarks

Characterizing the models used by health students to refer to immunological processes, in order to identify the main obstacles to learning this conceptual field, as well as considering the explanatory models of students as mediators in the process of knowledge construction, are valuable tools to achieve deep student learning.

The analysis of the students' responses to the different situations presented during the educational intervention allows us to affirm that the models used by the students before and after the educational intervention use explanatory criteria of the scientific models used in immunology. Apparently, in the context of university education, and particularly in the teaching of phenomena related to immunology, the weight of previous ideas is more relative than in other levels of education. The previous knowledge that students have about these phenomena is so incipient that hardly influences the learning of the scientific models taught in the immunology class. Consequently, it is the concept itself – and its own relational structure – that initially guides its teaching.

The application of the classroom intervention made it possible for the students to use not only specialized terminology, but also to make explanations at the cellular and molecular levels of the phenomena studied. The change in the uses of languages, the explanatory force and the conceptual demand in the explanations given by the students are indicators of the achievement of deep learning. In our research, identifying the initial explanatory models of the students, characterizing their obstacles to learning and planning accordingly the teaching actions aimed at learning is a strategy to improve teaching.

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