Tunisian pupils' and students' views on the body's immunity

RIDHA BOUZAZI[1], ZOUHAIER HARRATH[2], ABDERRAZAK MAAROUFI[3]

[1]DISEMEF Doctoral School
ECOTIDI Research Unit (UR 16ES10)
Higher Institute of Education and Continuing Training
Virtual University of Tunis
Tunisia
ridhabouzazi@gmail.com

[2]AME Laboratory
Carthage Higher Institute of Childhood Education
Carthage University
Tunisia
zouhaierharrath@yahoo.fr

[3]Laboratory of Veterinary Epidemiology and Microbiology (LR 16 IPT 03)
Pasteur Institute of Tunis
Tunisia
abderazzak.maaroufi@pasteur.tn

ABSTRACT
The research focuses on studying the conceptions that pupils and students have about immunity at different levels of education in Tunisia: The first year of secondary school, the fourth year of secondary school in the Experimental Sciences section, and the final year of the Life and Earth Sciences (LES) degree at the university level. The objective is to identify and analyse learners' conceptions of immunity and how they evolve across different educational levels. The study acknowledges the existence of pre-scientific conceptions held by students and recognises the importance of addressing these conceptions as potential obstacles to effective learning. The data was collected through questionnaires administered to the learners, and the analysis includes both quantitative (percentage calculations) and qualitative (categorisation of open-ended responses) methods. The results indicate that a significant number of pupils and students harbour inaccurate understandings of immunity, demonstrating persistent resistance to correction despite formal instruction.

KEYWORDS
Immunity, conceptions, misconceptions, epistemological obstacles

RÉSUMÉ
Cette recherche porte sur l'étude des conceptions des élèves et des étudiants sur l'immunité à différents niveaux d'enseignement en Tunisie : la première année du secondaire, la quatrième année du secondaire, section sciences expérimentales, et la troisième année de la licence Sciences de la Vie et de la Terre (SVT) au niveau universitaire. L'objectif est d'identifier et d'analyser les conceptions des élèves sur l'immunité et leur évolution à travers ces niveaux d'enseignement. L'étude reconnaît l'existence de conceptions préscientifiques chez les élèves et

reconnaît l'importance de les aborder comme des obstacles potentiels à un apprentissage efficace. Les données ont été collectées au moyen de questionnaires administrés aux apprenants et l'analyse regroupe des méthodes quantitatives (calculs de pourcentages) et qualitatives (catégorisation des réponses ouvertes). Les résultats indiquent que de nombreux élèves et étudiants ont des idées fausses sur l'immunité, qui résistent au changement même après l'enseignement.

MOTS-CLÉS
Immunité, conceptions, conceptions erronées, obstacles épistémologiques

PROBLEMATIC

One of the constraints on science education is the existence of pre-scientific conceptions among learners (Brunet, 1998). These conceptions play a decisive role in education and, in most cases, are incompatible with scientific models (Ravanis, 2020). Dispelling them through new learning may be difficult and could pose serious epistemological barriers that hinder the understanding and appropriation of scientific concepts. So, addressing these obstacles in learning activities is the only guarantee of assimilating new knowledge (Rumelhard, 1997). Because they are upstream of each learning, misconceptions are an effective tool in researching and identifying potential barriers to learning. This issue comes up when immunity is being taught (Aidoun, Zerhane, et al., 2016; Rumelhard, 1990a). The complexity of the immune system and its specificities (Bernard, 2006) are sufficient to justify the need to take into account prior conceptions when teaching this theme if learners are to effectively construct the targeted concepts. In particular, the strong link between immunology and the medical field (Rumelhard, 1992) is likely to induce misconceptions in pupils and students.

Our purpose in this work is to bring out and study conceptions on immunity at three different levels of education in Tunisia: the first year of secondary school, common core; the fourth year of secondary school, Experimental Sciences section; and the final year of the bachelor's degree in Life and Earth Sciences (LES) at higher education. We want to extend the research to these three levels to find out if there is a conceptual change when moving from one level to the other or, on the contrary, to identify possible false conceptions that resist and that reflect epistemological obstacles that must be taken into account in the teaching-learning sequences. It is well recognised that misconceptions about the immune system, its functions, and its mechanisms exist among both learners and teachers (Aidoun, Mahdi, et al., 2016; Rumelhard, 1990b). Our research question is: What conceptions of immunity do secondary and tertiary students have, and how are they evolving?

THEORETICAL FRAMEWORK

This work is part of the field of science didactics, more precisely that of the teaching-learning processes of biological concepts, where the aim is to identify and explain the difficulties encountered by learners in the appropriation of new concepts. According to constructivist theory (Piaget, 1937), each new learning is the result of an active construction that erases or modifies and develops previous knowledge related to the object of study. The term 'conceptions' refers to the preconceived ideas brought by learners to class sessions (Giordan & De Vecchi, 1987), i.e., everything they have in mind about scientific knowledge or a technical fact (Simonneaux & Simonneaux, 2014). These ideas are most often false and are then referred to as initial or alternative, or erroneous conceptions. In didactics, the term 'conception' is

central and is preferred to its synonym 'representation' because it is less polysemic, places more emphasis on the individual, and implies a constructive activity on his part (Abrougui & Clément, 1996).

Learning involves the activity of the individual that enables him to abandon some of his prerequisites or some of his beliefs and ideas, and to modify others to install new scientific knowledge in his mind. Thus, successful learning underlies a conceptual change in the learner (Duit et al., 2013). However, this conceptual change is not easy, due to the resistance to change and the tenacity of some prior conceptions. According to (Bachelard, 1993), alternative conceptions can be classified into broad categories that reflect simple ways of thinking opposed to the acquisition of scientific knowledge, thereby determining epistemological obstacles. This is where the importance of teachers taking into account learners' initial conceptions lies: identifying possible epistemological obstacles and designing pedagogical activities to overcome them. This is what is referred to as the teaching of objective-obstacle, a concept invented by Martinand (Geminard, 1987).

In science education research (didactics of science), studies indicate that students' conceptions of immunity frequently rely on simplistic military metaphors, where antibodies and microbes are viewed as direct adversaries. While these naïve representations may be intuitive, they tend to obscure the complexity of underlying cellular and molecular (Ayrinhac & Bru, 2019; de Andrade et al., 2016). Among university students, several key confusions persist, such as the differentiation between innate and acquired immunity, or misconceptions concerning the distinct roles of various immune cells (Zerhane et al., 2002). The evolution of these initial conceptions of immunity necessitates a confrontation between students' initial ideas and scientific models, a process that is often facilitated by inquiry-based scientific approaches and the introduction of complex problems (de Andrade et al., 2016; Stranford et al., 2020).

The conceptual obstacles encountered by students, such as the tendency to perceive the immune response as strictly linear and sequential, constitute a major impediment to the appropriation of scientific knowledge. To overcome these limitations, it is essential to implement contextualized pedagogical strategies that place immune mechanisms within concrete, real-world situations (Ben Jomâa, 2018; Stranford et al., 2020).

STUDY METHODOLOGY

Data collection

Data on conceptions of immunity were collected through questionnaires addressed to three samples of learners. The questionnaires were administered after teaching in school setting, to focus on conceptual change and resistant misconceptions. These questionnaires are self-administered.

TABLE 1

The populations surveyed

The educational level and age group	Number of respondents	Establishment	Teaching staff
First year of secondary school, ages 16 to 17	26 pupils	Gafsa Secondary Model School	Teacher specialised in LES, tenured, and with great seniority
4th year, Experimental Sciences, 18 to 21 years old	31 pupils	Elemtiez Secondary school in Tozeur	Teacher specialised in LES, tenured, and with great seniority
3rd year of LES bachelor's degree, >21 years old	48 students	Gafsa Faculty of Science	Assistant professor, specialised in immunology, and tenured

The objective is to check the degree of mastery of the concepts studied by pupils and students and to bring out possible false resistant conceptions. The final formulation of the items for each questionnaire was made after experimentation with a small sample of learners and validation by an expert. The characteristics of the target populations are summarised in Table 1.

Data processing

The objectives of the survey have been translated into questions. Each question, therefore, refers to a variable that can take several forms. These modalities are represented by the respondents' responses. The analysis of these responses makes it possible to compare the results obtained with those assumed. This is a mixed analysis, quantitative descriptive, based on the calculation of the percentages of response modalities, and qualitative, looking for meaning in the content of the answers to the open-ended questions, answers that will then be classified. The qualitative and quantitative data from these questionnaires will be expressed in figures and tables.

RESULTS

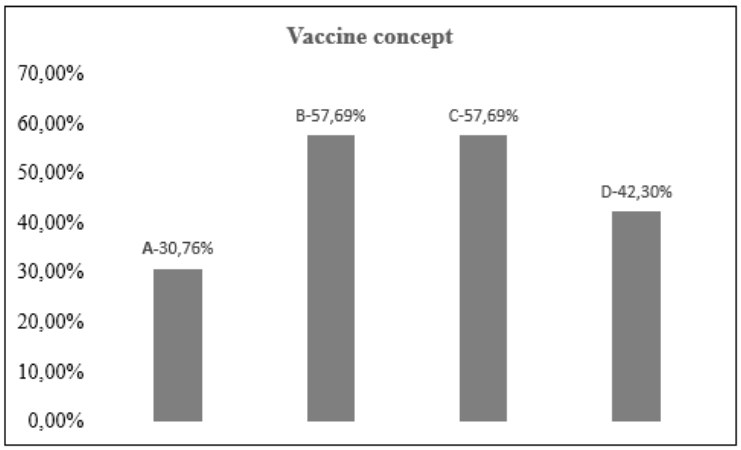
Results of the first year of secondary school questionnaire

The questionnaire for pupils in the first year of secondary school includes questions on the definition of immunity and related concepts, questions about the types of immunity, and questions about its applications.

The vaccine concept

Pupils were asked to check off each correct answer to a multiple-choice item that related to vaccination (Figure 1). Of 26 pupils, 15 (57.69%) gave the correct answer (C), but of these, 12 pupils associated the true proposition C with one of the other three propositions that are false. Thus, only 3 students (7.69%) selected the only expected answer.

FIGURE 1



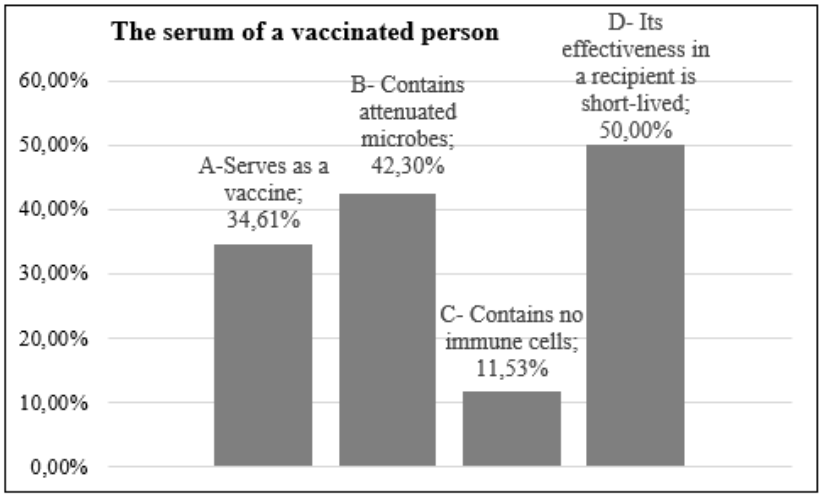
The meaning of the Vaccine concept in first year of secondary school. A: Mediation like any other. B: Long-lasting preparation. C: Preparation based on the infectious agent. D: Recognizes the antigen upon each contact

About serotherapy

We gave the pupils four proposals on serum and serotherapy. The results are shown in Figure 2. The correct answers are C and D. The number of pupils who selected option C is very small (2 pupils), while those who chose option D represent half of the group. The comparison of the

percentages of responses C and D is subject to questioning. Only two pupils both correct answers, C and D (7.69%) of the total enrolment, which implies that most of the pupils involved in this survey did not understand what serotherapy is.

FIGURE 2

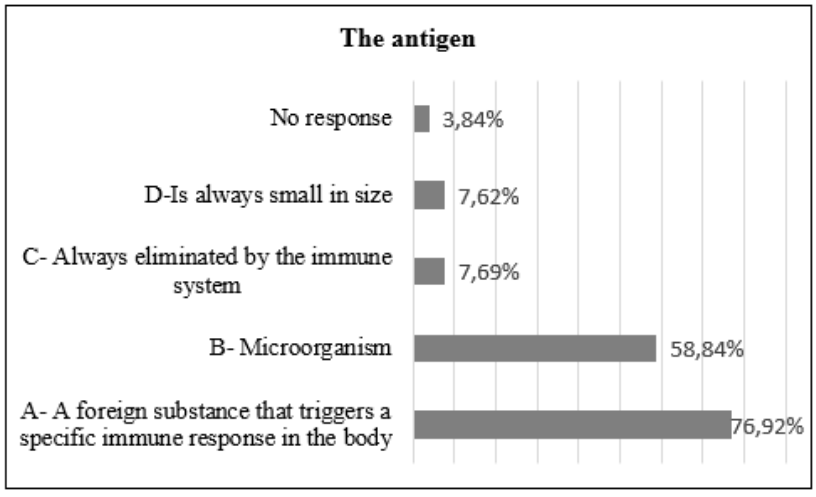


Serotherapy as seen by pupils in the first year of secondary school

Antigen concept

A multiple-choice question about the meaning of the term antigen is asked (Figure 3). Although many pupils (76.92%) chose answer A, which is true, a relatively small proportion (7.69%) chose answer D, which is also correct. No pupil selected the two correct expected answers, A and D. On the other hand, about 3/5 of the group surveyed chose the false proposition B, and 2 students (7.69%) answered with C, which is false too.

FIGURE 3

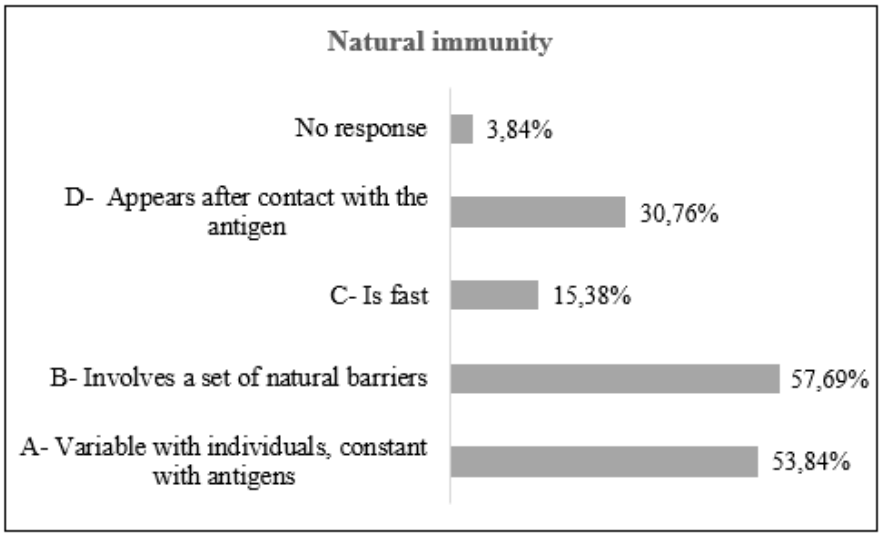


Antigen concept according to first year of secondary pupils

Natural immunity

The question focuses on the definition of immunity and some of its characteristics (Figure 4). According to 30.76% of pupils, innate immunity and adaptive immunity are the same.

FIGURE 4



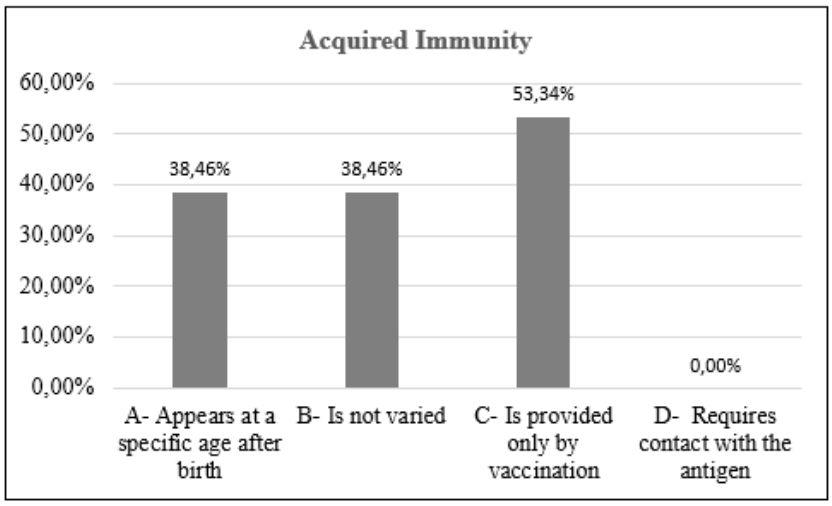
Innate immunity conceptions in first year of secondary pupils

Acquired immunity

The goal is to find out whether or not pupils correctly define acquired immunity and whether they know its main properties (Figure 5). Two major remarks should be highlighted:

- Acquired immunity is the result of vaccination alone. This idea is common to more than half of the group involved in this research.
- The only expected answer, which is option D, was not chosen by any student.

FIGURE 5



Acquired immunity as perceived by pupils in first year of secondary school

The functions of the immune system

We asked pupils only one open-ended question in this survey: "*In your opinion, what are the main functions (roles) of the immune system?*". The analysis of the pupils' written answers reveals a wide range of responses, which can be broadly categorised into two main groups. The first category focuses on understanding and explaining the immune system's role in defending and protecting the body. These responses likely delve into the different components of the immune system, such as white blood cells, antibodies, and the process of immune response. The second category revolves around exploring the various means by which immunity is

achieved. This may include discussions on vaccinations, natural immunity, herd immunity, and other mechanisms that contribute to the body's ability to fend off pathogens. The first category of response is related to final thinking, while the second reflects mechanistic thinking since it refers to the mechanisms and means of immunity. Nevertheless, these two main categories are broken down into subcategories that need to be explained and discussed (Table 2).

From these results, we can draw the conclusion that the role of the immune system is limited to a single protective function. This particular function appears to be poorly understood by a significant number of respondents. It is worth noting that the function of monitoring the overall integrity of the body was not mentioned by the pupils who participated in the survey.

TABLE 2

The functions of the immune system according to first year secondary school pupils

Main Categories	Subcategories	% of Responses	Sample answers
Purpose-Driven Response: Protective Role	General body protection	38.46	- "Protecting the individual's body and health." - "Protecting Man" - "Protecting Life"
	Protection against pathogens in general	19.23	- "... protect the body from pathogens for its health."
	Protection against diseases and germs in general	23.07	- "Protecting the body from disease." - "Protect the body from all germs."
	Protection against infectious agents and all antigens	7.69	- "Protect the body from any antigen." - "The immune system protects the body against harmful microbes and viruses."
	Protection against viruses (only)	3.84%	- “ Security against viruses ”.
Response focused on the mechanisms and means of protection	Mechanisms and means.	11.53%	- "The main function is phagocytosis." - "It releases antibodies against pathogens."

Results of the fourth year Experimental Sciences questionnaire

For the fourth-year Experimental Sciences questionnaire, the items relate to the following topics: The definition of immunity and the immune system, the functions of the immune system, the types and mechanisms of immunity, and finally, the practical applications of immunological knowledge. In the following, multiple-choice questions and pupils' answers with relative percentages are presented in tables. Pupils should check off any proposition they believe to be true. So, due to multiple responses, the sum of the percentages is greater than 100. Subsequently, a series of dichotomous questions is proposed. The pupils must answer with ‘True’ or ‘False’ (Table 10).

The concept of a vaccine

The results (Table 3) indicate that among one-third (32.26%) of the pupils surveyed, there are confusions and problems in the definition of the concept of vaccine.

TABLE 3

The concept of a vaccine among pupils in the fourth year Experimental Sciences section

A vaccine …	
A. is a preparation based on an antigen and antibodies	9.67%
B. is a long-term preparation	22.58%
C. is a preparation based on the infectious agent	**74.19%**
D. specifically recognises the antigen on each contact	6.45%
Answer C selected alone by respondents	**67.74%**

About serotherapy

Most students gave the single correct answer, B, but for a quarter of the group, it seemed that vaccination and serotherapy were synonymous (Table 4).

TABLE 4

The concept of serotherapy among pupils in the fourth year Experimental Sciences section

The serum of a vaccinated individual…	
A. can be used to vaccinate other people	16.12%
B. contains immune proteins	**77.41%**
C. contains cells that produce antibodies directed against the antigen in question	16.12%
D. has long-term efficacy in the recipient	6.45%
Answer B selected alone by respondents	**74.19%**

The Antigen concept

The results (Table 5) show that 29 pupils (93.54% of the entire group) do not know the exact definition of the concept of antigen. They confuse the antigen with anything foreign to the body or with tissue markers.

TABLE 5

The concept of antigen among pupils in the fourth year Experimental Sciences section

Un antigen…	
A. is a molecule with immunogenic power	84.64%
B. is a molecule foreign to the body	6.45%
C. is a molecule located on phagocytes	51.61%
D. is a molecule located on lymphocytes	**16.12%**
Answer D selected alone by respondents	**6.45%**

The agglutinogens

The majority of pupils struggle to distinguish between tissue markers and markers of the ABO blood group system, making it difficult to understand immunological identity (Table 6).

TABLE 6

The concept of agglutinogen among pupils in the fourth year Experimental Sciences section

Red blood cell agglutinogens…	
A. are membrane glycoproteins	**100%**
B. are specific to each individual	70.96%
C. are of three types	**32.25%**
D. are of two types	74.19%
Only answers A and C selected together	**6.45%**

The case of identical twins

No student gave the exact answer expected (Table 7). The vast majority of respondents selected three or four options simultaneously, which explains the high percentage of each answer.

TABLE 7

The identical twins according to pupils in the fourth year Experimental Sciences section

The identical twins…	
A. are membrane monozygotic	**87.09%**
B. certainly have the same HLA	93.45%
C. have the same blood type	**96.77%**
D. between them, the graft is always 100% successful	70.96%
Only answers A and C together	**0.00%**

Clonal selection of lymphocytes

More than three-quarters of students either did not choose the expected answer D alone, or if they did select it, they combined it with other answers that were incorrect (Table 8).

TABLE 8

Clonal selection of lymphocytes according to pupils in the fourth year of the Experimental Sciences section

Clonal selection of T8 lymphocytes…	
A. can be caused by direct contact with a virus	12.90%
B. is carried out after clonal selection of B lymphocyte	48.38%
C. requires the presence of interleukin 2	74.19%
D. is done by contact with a CPAg (antigen presenting cell)	**90.32%**
Only answer D	**22.58%**

Help for an Immune Deficient

Less than a quarter of all students gave the only expected answer, D. A much larger number ignored it or combined it with other incorrect answers (Table 9).

TABLE 9

Interpretation of a pathological case by pupils in the fourth year of the Experimental Sciences section

Human antibodies injected into a baby suffering from severe immune deficiency...	
A. are considered foreign antigens	9.67%
B. stimulate the immune system	41.93%
C. prevent infectious diseases	74.19%
D. confer on the body short-term passive immunity	**54.83%**
Answer D alone	**22.58%**

A second series of questions to be answered by ‘True’ or ‘False’ was proposed to the pupils. Table 10 summarizes the questions and the results of the answers. Whatever the question asked, it is easily noticeable that the recurrence of false answers exceeds a minimum of 35% which corresponds to a significant proportion of pupils who convey in their writings problems of learning the concepts related to the immunity of the organism: Confusion between autoimmunity and defense against pathogens, emergence of the social representation of microorganisms as all being pathogenic, external origin of the antigen, confusion between markers of the self and antigenic determinants, the mechanisms of immune reactions are poorly assimilated.

TABLE 10

Responses from fourth-grade Experimental Sciences pupils to questions on various aspects of immunity

Items	Answers		
	True	**False**	**Expected answer**
1. In case of autoimmunity, the body is unable to defend itself against infectious agents	64.51%	**35.48%**	False
2. The body can tolerate microorganisms	**51.61%**	48.38%	True
3. The "non-self" is always of external origin	35.48%	**64.51%**	False
4. T lymphocytes recognise the antigen as it is	35.48%	**64.51%**	False
5. Lymphocytes from the spleen of a mother infected with a V virus can experimentally destroy cells from her V-infected fetus	83.87%	**16.12%**	False
6. The difficulty of vaccination against certain microbial and parasitic diseases is explained solely by the resemblance of our markers to those of certain pathogenic agents	48.38%	**51.61%**	False

Results of the third year LES degree questionnaire

Questions cover the roles of the immune system, discrimination of self and non-self, applications of immunology, and the relationship between innate and adaptive immunity.

Functions of the immune system

We asked students to specify the functions of the immune system. We then noted varied responses that we classified into categories indicated in Table 11. Two main categories are identified: Answers that converge on the function of defence and protection of the organism ensured by the immune system, and others that focus on the function of preserving the integrity of the organism. Responses in the first category are much more frequent than those in the second category, although these two functions of the immune system are of equal importance. Each of these two main categories is subdivided into subcategories that provide more details on the function of the immune system indicated in each response.

TABLE 11

The functions of the immune system, according to LES students

Main categories	Subcategories	% of responses	Example responses
Protective role	General protection of the body against all dangers	79.15	- "…protect the body." - "…Protection against all diseases." - "…protection against pathogens." - "Protection against external aggression." - "Protection against viruses and bacteria."
	Protection against antigens	20.83	- "Defence against non-self-elements." - "Protection of the body against antigens."
	Protection against the "altered self"	8.33	"The immune system serves to protect our body against external attacks and abnormal or even cancerous cells."
Preservation of the integrity of the organism	Protection against body dysfunction	8.33	"Protect against internal dysfunction"
	Self-tolerance	8.33	"Facilitate transplants"

The concept of antigen

When we asked students, "*What do you consider an antigen?*", their answers expressed a widespread range of interpretations (Table 12). Interestingly, one of them held the essential definition of an antigen as a foreign substance that provokes a targeted immune response. While a few answers imply pathogens or damaging agents, they frequently lacked the specificity and experimental basis anticipated at this level. This gap suggests a conceptual misunderstanding that could be explained.

TABLE 12

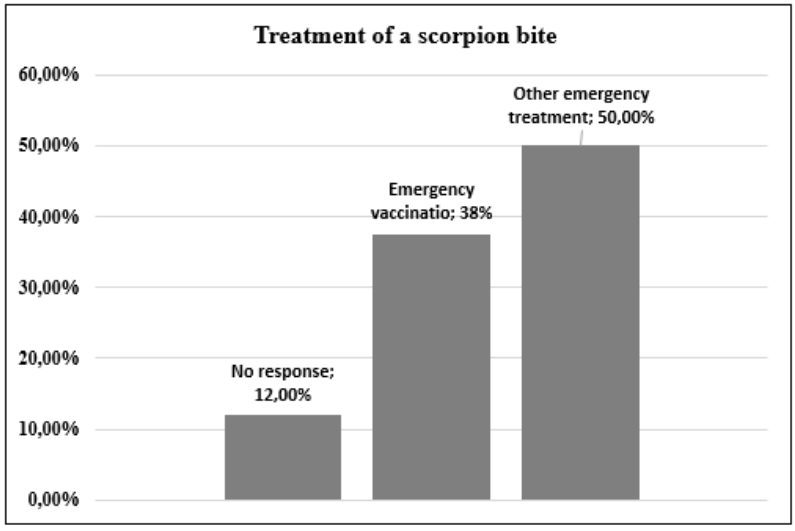
The concept of antigen, according to LES students

Types of definitions	% of responses	Examples
False definitions	37.5	- "The antigen is what causes immune dysfunction" - "The antigen is anything unknown to the immune system"
Definitions by synonyms	16.66	"The antigen is the non-self"
Incomplete definitions	58.33	- "The antigen is what is recognized by antibodies or certain immune cells"

Immune response support

We asked students to choose between two courses of action in an emergency where a person is bitten by a scorpion: emergency vaccination or other emergency treatment (Figure 6). The results show that half of the students who participated in this survey (38% + 12%) have no idea about vaccination and serotherapy, or do not know how to correctly distinguish between the two applications.

FIGURE 6



What to do in the event of a scorpion bite, according to LES students

Relationship between natural and adaptive immunity

To the question "*Can you explain the link between innate and adaptive immunity?*", the students' responses, grouped into three categories (Table 13), reveal that none correctly explained this relationship. Two suggested that adaptive immunity was triggered by innate

immunity, while six did not respond, reflecting a lack of understanding of the link. These findings raise concerns about the effectiveness of the instruction provided and highlight the need for clarification.

TABLE 13

The link between natural immunity and acquired immunity, according to LES students

Link types	% of responses	Examples
Linear causal relationship	33.33%	- "Innate immunity activates adaptive immunity" - "Innate immunity comes before adaptive immunity"
Circular dynamic relationship	04.16%	"The two complement each other"
Separation	50%	- "Innate immunity involves molecules, antibodies, and lymphocytes. Adaptive immunity develops immune memory" - "Both innate and adaptive immunity protect the body"

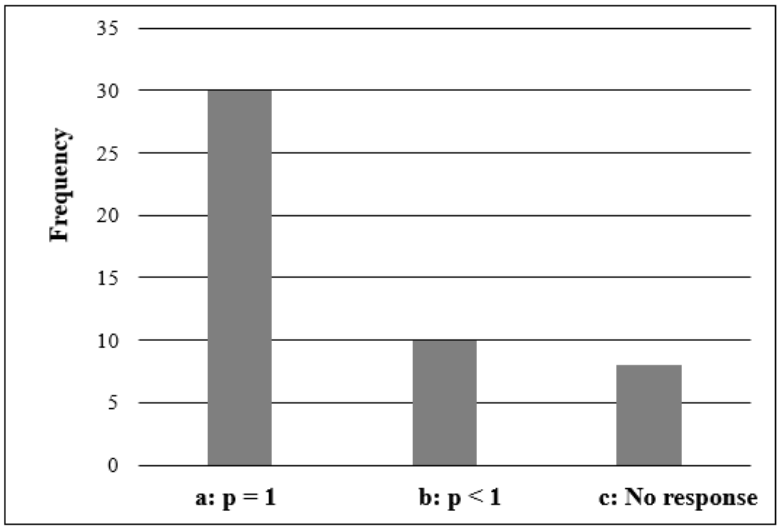
The altered self

In a closed-ended question, students were given the following statement, which they had to answer affirmatively or negatively: "*Our immune system does not attack the body's cells regardless of their state*". The majority of students (87.5%) gave the correct answer, while the remainder (12.5%) gave the statement as true; however, they constitute a significant part.

Histocompatibility

We asked the students surveyed to assess the probability of a successful transplant between two people with the same A^+ blood type. Figure 7 shows the results**.**

FIGURE 7



Evaluation by LES students of the success rate of an organ transplant between two individuals with the same blood group A^+

More than 30 students have confusion between agglutinogens and HLA tissue markers.

DISCUSSION

This questionnaire study allowed us to raise several observations concerning problems of assimilation by learners of the immunological concepts taught at the three levels of education (Table 14). For the majority of the questions asked, the correct answers required are sporadic, which reflects weaknesses of various sources among pupils and students.

TABLE 14

Summary of questionnaire results (only responses containing anomalies are considered)

	1st secondary year	**4th year Exp. Sc.**	**LES3**
Functions of the immune system	General protection against all pathogens	Confusion between the defence function and the function of controlling the integrity of the organism	Body protection against all dangers
Antigen concept	Antigen is synonymous with a microorganism	-Antigen is synonymous with a foreign substance. -Confusion with 'self' markers	-Antigen = non-self. - The antigen is responsible for immune dysfunction
Discrimination between 'self' and 'non-self'	NB: Not covered in the program	- Confusion between 'self' markers and antigens. - Agglutinogens are the major 'self' markers	- Agglutinogens are the major markers of self
Immunology applications	- The vaccine is an ordinary medicine - Confusion between vaccination and serotherapy	Confusion between vaccination and serotherapy	Confusion between vaccination and serotherapy
Other remarks	Innate and acquired immunity are poorly distinguished	Lack of exploitation of genetic knowledge	Innate immunity and acquired immunity are separated

About the functions of the immune system

From the first year of Secondary school to the third year of the LES degree, the prevailing idea is that the immune system has a single mission, which consists exclusively of defending and protecting the organism. This defence is directed against all external attacks, especially those from microbes. Tolerance of the 'self' is extremely rare in the responses of the respondents. In 64.51% of pupils in the 4th Experimental Sciences, autoimmunity suppresses the defence function against pathogens, implying that for them, the tasks of preserving the integrity of the organism and the defence function are confused. Similar findings have been made elsewhere in research involving pupils, students, and even teachers (Elmazouni et al., 2018; Mosothwane, 2009). This model of immunology focused only against extrinsic aggressions is told with apiece strong link between immunology and the medical field (Faure, 1993; Vivier & Lévy, 2001).

On the concept of antigen

Antigen is a fundamental concept in immunology. If learners do not assimilate it correctly, the consequences will be harmful to their learning and understanding of the mechanisms and properties of the body's immune responses. Except for a tiny fraction of all questionnaire participants, who approximate the exact definition of this concept, the latter is misrepresented among the others:

- It is synonymous with 'non-self', although counter examples exist (Gohau, 1990), including the tolerance of intestinal microflora or spermatozoa in the female genital tract or the fetus in the uterus, which is a kind of semi-allogeneic transplant, etc. Moreover, not everything that is 'non-self' is necessarily an antigen.
- Antigen is equivalent to a microbe. This impression is twofold: First, not all antigens are microbes; toxins, for example, are antigenic substances. This misconception then hides another, that of the social representation of the concept of microbe, which is linked to infections and diseases (Boisvert, 2017; Rene, 1993).
- The antigen is confused with the marker of 'self'; therefore, the students of the 4th year of Experimental Sciences locate it on the lymphocyte membrane. This is a misconception among students that arises due to how a concept was taught, rather than a failure of the students themselves (Brousseau, 1998). The teaching style adopted does not support the active construction of scientific concepts by learners.
- The antigen is what causes the immune system to fail. Here, the perception of an antigen is lowered to that of an allergen or some different entity or body that weakens the immune function.

About the distinction of self and non-self

In the responses of fourth year Experimental Sciences pupils and third year LES students to questions referring to the discrimination of self and non-self, we found a variety of incorrect answers. This can be explained by the students' difficulties learning the concepts of self-markers and antigens, concepts that are found in the study of immune response mechanisms. Thus, according to 83.87% of fourth year Experimental Sciences pupils, cells taken from the spleen of a mother infected with a V virus can, in vitro, destroy cells from her fetus that are infected with V. Here, the students consider the mother and her fetus to be of the same self.

Similarly, according to 12.5% of third year LES students, the immune system always tolerates the body's cells. The altered self-concept was therefore not taken into account in their responses due to a lack of understanding of basic concepts such as biological identity markers. One of the difficulties encountered by students, which is revealed in their responses to the questions posed, is that they do not correctly distinguish between antigen and self-markers. We thus counted 16 responses from pupils in fourth year Experimental Sciences to one of the questions (51.61%) who stated that the antigen is located on the membrane of lymphocytes.

These anomalies in learning the fundamental concepts of immunology have several origins. Some relate to the very specificity of this discipline (Bernard, 2006), particularly its interdisciplinarity and the multi-scale complexity of the immune system (Thomas-Vaslin, 2016); others relate to the teaching model and the pedagogical approach adopted (Sacadura et al., 2010). Still in the same context, we identified in the responses to questions related to the discrimination of self and non-self the misconception that red blood cell agglutinogens are major markers of self. Indeed, 70.96% of the 4th year Experimental Sciences pupils surveyed consider them to be so. The same remark is made by 62.5% of third year LES students who affirm the total success of an allograft between two subjects of blood group A+. This misconception can be explained by the social representations relating to blood and blood groups that are conveyed by the pupils and students in their responses.

On the applications of immunological knowledge

In the three levels of education considered, confusion between vaccination and serotherapy is observed. These upheavals are thought to reflect distortions in the didactic transposition, which must be addressed in the classroom (Bengloan & Nichele, 2012). These confusions are noted in the definition of a vaccine and also in the properties of the two immune response aids.

Moreover, among almost a third of the first year Secondary school pupils, the vaccine is a curative medication. This representation of the concept is echoed among a portion of third year LES students (38%), who prescribe emergency vaccination to treat scorpion bite poisoning, thus assigning the vaccine a curative role. This is therefore a persistent misconception that most likely reflects an obstacle to learning among learners. The same misconception is held by students in Morocco (Aidoun, Mahdi, et al., 2016).

On the two types of adaptive immunity

Most first year secondary school pupils have some true knowledge about immunity, especially natural immunity, but this knowledge is accompanied by some misconceptions, particularly about the properties of the two types of immunity.

As for fourth year Experimental Science pupils, approximately 39% of them affirm the recognition of native antigens by T lymphocytes. We therefore deduce that for these pupils, the link between natural and acquired immunity is not considered. The same observation was made among third year LES students, where they completely omit this link in their responses to the question "*Can you explain the link between innate immunity and adaptive immunity?*". There are several reasons why students find it difficult to accurately define the two types of immunity, understand their features, and recognise their relationship:

- Most young people are global learners; they just keep superficial ideas of things. In particular, they rely on memorisation without worrying about understanding facts and events (Moore et al., 2002).
- In the first secondary year, there is a focus on natural immunity. Acquired immunity is treated without any input into the mechanisms. The rich, condensed and new scientific vocabulary is likely to negatively influence learning efficiency. As for the 4th Experimental Sciences, only adaptive immunity is studied without the resumption of natural immunity. There again, the polysemy of scientific vocabulary and its ambiguity are remarkable. Finally, for third year LES students, natural immunity and acquired immunity are studied in detail. The difficulties of the students are explained by the overload of the content and the style of teaching.

CONCLUSION

The survey we conducted with secondary school pupils and final year undergraduate students in Life and Earth Sciences (LES) about their prior learning and understanding of immunity provided us with important insights that touch on various aspects of teaching this biological function:

- At all three levels considered, learners faced difficulties in their learning, especially with the mechanisms of immune responses and the complete lack of understanding of the boundary between natural and adaptive immunity. These difficulties become more pronounced as they move from one level to the next due to the condensed curricula and teaching styles.
- The dominant explanatory model of the organism's immunity is the self/non-self-model. This is an exclusively biomedical view, noted even among students. However, this model has its limitations (Truchetet et al., 2013). According to the respondents, immunity corresponds to an occasionally triggered, outward-facing function (Rumelhard, 1990a).
- Persistent misconceptions emerged: Antigen is synonymous with microbe; vaccines serve as curative medication; and red blood cell agglutinogens determine each person's identity.
- The conceptual shift is minimal. Learners' linguistic deficiencies (Mosothwane, 2009), the specificities of immunological knowledge (Bernard, 2006; Rumelhard, 1990b), curriculum overload, and the teaching approaches used all push students to memorise to pass exams rather than to understand (Moore et al., 2002).

For quality teaching that promotes conceptual change and the extracurricular transfer of acquired knowledge, we recommend:
- A curriculum review that respects the horizontal and vertical coherence of teaching complex concepts such as immunity.
- The adoption of a teaching approach that takes into account the complexity of concepts, their interdisciplinarity, and learners' initial conceptions. Here, a more practical, systemic approach is desired.
- A break with the current assessment system and a shift toward a new one that values learner effort, skills, and performance in problem-solving, and that motivates learning.

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