Important skills mobilized by an inquiry-based activity for the formation of Immunologists

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Abstract: The training of scientists for immunology can begin in undergraduate classes. Here we report our experience in the development and application of an inquiry-based learning activity with these characteristics for students of the biological sciences course. The results showed that the groups of students, when performing the inquiry-based learning activity, mobilize important epistemic operations for the construction of analyses of justifications and conclusions of the activity in various levels of epistemic status. The approach to immunology topics can be associated with an inquiry-based learning, with simple activities, low cost and that mobilize important skills of scientific literacy for the basic training of one in the field of immunology research.

Keywords: teaching immunology, inquiry-based learning in immunology, training new immunologists.

Introduction

Immunology is an area of biological sciences that has grown in recent years. It is an area of rising science, and it needs more specialized and more qualified scientists for the next generations. Immunology topics have a strong personal appeal and have a significant presence in students' daily lives, for example, immunization issues, treatment with immune-derived products, or autoimmune diseases (Hannum, 2016). Therefore, it is common that the career of an immunologist already arouses interest in students still in higher education. As in some areas of the biological sciences, dealing with microscopic and molecular situations, much of the knowledge in Immunology is produced through direct or indirect technical experiments and later explained by conceptual models. Thus, the formation of a scientist in this area must go through the development of skills in the construction, development and interpretation of experiments with these characteristics. Besides developing the ability to articulate ideas, make connections between the data found with knowledge, propose premises, and a coherent argumentation for the writing of a scientific article. However, despite the students' interest in immunology, there are several difficulties with the content. The first difficulty is that much of the knowledge in immunology is abstract, derived from microscopic and molecular phenomena that cannot be viewed directly and easily. Another point is that immunology is an interdisciplinary science and the understanding of its contents requires knowledge of other natural science areas. Also, for teaching institutions and for immunology teachers, the difficulty with the use of vertebrate animals during practical classes, the high cost of specific reagents and time of classes. The experiments for the visualization of in vitro or in vivo phenomena in Immunology demand, mostly, many hours of accomplishment and getting results, which are often incompatible with the hours available in the hourly schedule of the graduation courses in universities around the world.

Science education presents several perspectives that can be associated with the teaching of immunology for higher education. The teaching of immunology, most of the time, is only theoretical exposition of readymade concepts or readings of scientific articles making it impossible for the student to live a real scientific experience. The student stays in a passive position only receiving an huge theoretical content. Inserted in an experimental science, the immunology student needs to gain skills pertaining to scientific literacy and still perfect them for a more particular look at immunology. For example, an immunologist is challenged daily with experiments that generate quantitative and qualitative data, which are distinct, and must be capable of interpreting and constructing a conceptual model. Therefore, it is necessary to promote a specific scientific literacy in Immunology that is the learning of logic and the specific conceptual and technical language of this science. For instance, the word 'memory' assumes other dimensions of meaning in immunology in relation to other natural sciences. Besides the biological model to show the 'immunological memory' to be permeated by techniques and methodological procedures particularly developed in immunology. A structure that simulates learning by scientific research brings the subject to the 'scientific spirit' leaving the passive posture aside to a dynamic way of learning by promoting student autonomy. This methodological framework is a proposal that addresses a construction or reconstruction of knowledge inserted in a context similar to scientific research guided by a teacher. Studies show that students who take part in this strategy have gained important scientific abilities (Minner, Levy and Century, 2009). The inquiry-based learning science can be an interesting path to this goal.

The term inquiry-based learning science is often cited in the official texts of several countries as a recommended strategy to promote a desired in scientific education (NRC, NSF, AAAS, PCN). These texts share the idea that the use of this method in the classroom contributes to the appropriation of the student's procedural and epistemic knowledge of science (Duschl and Bismarck, 2016). Historically, the term inquiry-based learning is used within science education from different points of view - as authentic scientific activity, as an active process of students engaged in problem solving, and as a resource that teachers employ to give the student the opportunity to conduct research (Anderson, 2002; Minner et al., 2009) - of a single strategy. The NRC describes guiding elements of an inquiry-based learning activity for basic education. These are: i) student engagement in scientific query; ii) use of evidence to construct scientific explanations about the issues previously proposed; iii) evaluation and refinement of explanations in the light of alternative explanations; iv) communication and justification of the explanations that the students constructed (NRC, 2000). In addition, Blanchard (2010) ran four levels of research based on the subject (whether the student or the teacher) that performs three key activities: formulating questions, collecting data, and interpreting the data generated. The levels of research range from level zero, "verification" where very little autonomy is granted to the learner, through the levels of structured, guided research, to open investigations, in which the learner has the independence to conduct the three key activities (Blanchard et al., 2010).

However, several papers point to a great difficulty in promoting an authentic scientific investigation in the classroom, including in higher education. Anderson (2002) attributes part of this complication to the existence of multiple conceptions about science by teachers. Duschl and Bismarck (2016) initially recommend that the teacher be aware of what tools of authentic science could be used as a complement to the classroom research. For example, knowledge of research practices and how they lead to statements with unique status and methodological aspects, such as the meaning of the terms hypothesis and theories, is a basic prerequisite for a teacher to identify key questions in research planning for their classroom context. Some evidence suggests that even professors in university science courses are not sure how to translate their research ideas into a classroom context (Park Rogers and Abell, 2008). Some difficulty is attributed to the complexity of the proposal itself, given by the multiple definitions of teaching by research and its levels, and by structuring how much education should be provided to the student (Blanchard et al., 2010), factors that may be associated with the absence of a solid training of higher education teachers (Anderson, 2002). Rather than generating a scientific question to investigate in classrooms, the teacher should consider how this question - and the processes that will lead to the attempt to answer - could help in understanding the specific disciplinary elements by the student (Cunningham and Kelly, 2017; Kelly and Duschl, 2002; Kelly and Takao, 2002). In this way, talking about scientific literacy becomes fundamental. According to Sasseron (2015), scientific literacy is configured with the perspective of bringing to the student the specific elements of science and how they organize themselves as an activity that influences the sociocultural processes of a society. Latour and Woulgar (1986) have an important role in this context. They minutely describe scientific activity by its social character, in which individuals use data representation to construct convincing arguments during the persuasion of peers (Latour and Woulgar, 1986). In this negotiation process, a fine-tuning is made in the definition of what counts as valid knowledge in that culture (Cunningham and Kelly, 2017; Kelly, Chen and Prothero, 2000; Kelly and Takao, 2002,). Hence in the higher education environment the different areas of science are studied in depth for vocational training, we realize the importance of identifying the elements, practices and norms of "doing science" valid for the area (Kelly et al., 2000; Kelly and Licona, 2018). The planning of the research strategy must involve, first, an epistemic understanding of the importance of these elements for the construction of the knowledge of that specific culture. Considerations about typical forms of obtaining and representing data, selection of evidence, and proper disciplinary language are part of literacy from an area-specific perspective.

In view of these observations, how do we still encourage and develop potential immunology students still in undergraduate? How to mobilize specific skills and competences important for the development of students to think about Immunology?

In order to answer this question and comprehend the profile of the Brazilian research in teaching and education of immunology, Natale et al. (2019) analyzed 36 abstracts submitted to the Annual Meeting of the Brazilian Society of Immunology, between the years of 2010 and 2017. They observed a higher number of works related to content learning compared to other areas, e.g.: teaching training and history of science. In addition, those works mostly based their analysis on questionnaires and interviews, compared to the analysis of students' spoken and written discourse. The finds of Natale et al. (2019) show that it is necessary to better understand how students collectively shape the process of production of knowledge when submitted to the specific elements of immunology in higher education.

From the practic of a real teaching-learning problem in immunology classes for higher education that, in recent years we have developed several inquiry-based learning activities in immunology. The activity described and analyzed by Mello et al. (2019) provided students with experiences in two typical elements of immunology: experiment and abstraction. Briefly, students analyzed the numerical data that they got by the execution of experiments to find an answer to the inquiry problem on the subject (the complement system). The authors observed that the activity displayed the emergence of several epistemic practices in the students' reports. In addition, they favored the emergence of epistemic practices in those groups of students that received a previous training in the structure of a scientific argument. In a follow up (Seixas Mello et al., 2021) to these analyses, the authors described the argumentative pathway performed by students to transform (Latour and Woulgar, 1986) their experimental data in evidence. The finds show that some groups that performed experiments produced assertions that merely described the data without explaining how the numbers and charts might answer the question under investigation. There were groups that did not perform experiments but analyzed the raw data generated by others. Curiously, these groups displayed a higher number of links among the data, the hypothesis, the investigative context, and the investigative expectations, achieving an answer to the problem. As conclusion, the authors point that these kinds of analysis are helpful to allow professors and researchers to identify the cruciais points that deserve attention in the development of proposals to immerse students in the scientific practices (Mello et al., 2019).

In another activity described in Manzoni-de-Almeida and Trivelato, 2015, we realized that the theme of development of B lymphocytes was a problem of great difficulty for students, since it involves interdisciplinary knowledge beyond the pillar concepts of immunology, for example molecular mechanisms of DNA, RNA and protein synthesis from the areas of cellular biology and biochemistry. Another point is that there was no report in the literature that contemplated some practical activity for the classes with this theme. In the main textbooks of Immunology (Abbas, Lichtman and Pillai, 2008; Calich and Vaz, 2009) used in most of the Basic Immunology courses in the most diverse biological and health courses in Brazil and other countries, show that the concepts of mechanisms for generating the diversity of antibodies and other lymphocyte receptors are essential for the pillars of contemporary immunology. An interesting biological phenomenon in nature is how an organism can produce several molecules, of a similar chemical nature, but with the ability to recognize and distinguish different types of other molecules - whether they are foreign to the organism itself, with high specificity? This response was intended for the immunology that for years planned one of the most important concepts that underpin one of the pillars of the properties of gained immune responses is the concept of Specificity. Specificity ensures that distinct antigens trigger specific responses when they are recognized by specific B lymphocyte (BCR) receptors, or secreted soluble antibodies, and T lymphocytes (TCR). Receptors for adaptive immunity, both membrane, TCR and BCR, as well as secreted antibodies, interact with the epitopes of restricted size and which are characteristic of the antigen molecule that induced them. It serves as analogy the fitting of a key and lock. The lymphocyte receptors, and the secreted antibodies, are thousands of distinct protein molecules, which are formed by somatic recombination (Abbas, Lichtman and Pillai, 2008). The current thinking is that the diversity of antibodies is generated following several complex mechanisms of gene rearrangement that involve concepts beyond immunology, touching concepts of areas such as molecular biology, biochemistry and cell biology. Hence, the class on the generation of the diversity of antibodies and recognition receptors, as pointed out above, is extremely important for the understanding of the foundation of Immunology.

When carried out by the students, the activity induced the mobilization of important behaviors by the students, the so-called epistemic practices (Manzoni-de-Almeida, Marzin-Janvier and Trivelato, 2016) and the production of written arguments (Manzoni-de-Almeida, 2016) that are important for the exercise of scientific activity. We believe that higher education classroom should be a “frontier” where leading researchers, who are directly involved in building new knowledge, and students have contact and can share the same interest. The challenge is to think about the immunology class from new and realistic teaching proposals that focus on the development of important scientific skills for the progress of the career of immunologists, improving the professional potential of our undergraduate students.

Here our goal is to deepen the analysis of how our inquiry-based learning activity in Immunology can mobilize important cognitive operations in the students. For this we analyze the students’ speeches and characterize the epistemic operations during the specific moment of execution of data coming from qualitative (non-mathematical experiments) and quantitative (mathematical experiments) experiments of the Immunology area, for example, Northern blot and PCR, respectively. Our hypothesis is that students mobilize different cognitive operations to analyze experiments of a different scientific nature, which could reveal important pedagogical paths for training, teaching and learning in the training of researchers in epistemology of immunology.

Methodology

Execution of inquiry-based learning sequence

The inquiry-based learning activity was developed in a final of 10 classes of Immunology, taught by two specialists in immunology, for the 5th semester of the Biological Sciences courses (approximately 40 students total). They divided the total sequence into 2 parts. The first part was a sequence of theoretical classes with the content focus of the inquiry-based learning activity - development of B-lymphocytes and principles of the laboratory techniques used in basic research of Immunology; and the second part was the application of inquiry-based learning activity.

Parts of sequences	Classes	Immunology Contents	Content on the principles of techniques	Learning goals
1	1	Immunology Basics		Know, describe and define the structures, functions and mechanisms of the immune system; Know and use the principles of quantitative and qualitative techniques; Interpret biological (immunological) phenomena based on quantitative and qualitative techniques.
	2	Cells and organs of the immune system		
	3	Ontogeny of the immune system	Quantitative technique: PCR	
	4	Innate immunity		
	5	Inflammation: vascular phenomena and cellular migration		
	6	Complement system		
	7	Principal Histocompatibility Complex (MHC)		
	8	Processing and presentation of antigens		
	9	Activation of T and B lymphocytes	Qualitative Technique: Northern blot	
2	10	Practical class: Inquiry-based learning activity on the development of B lymphocytes		Know the problem and engagement in the research question; Explore and explain data; Elaborate and evaluate the understandings of the investigation.

Table 1.- Immunology course organization in the Biological Science course.

The inquiry-based learning activity developed in Manzoni-de-Almeida and Trivelato (2015) on the development of B-lymphocytes was applied in class 11 as described in Manzoni-de-Almeida et al. (2016). Briefly, the inquiry-based activity lasted 2 hours. Students were divided into 12 groups with 5-6 participants per group. For the execution of the activity, they divided the data set to be analyzed by the students into three categories according to the profile of the results to which the students would arrive. In the activity there were 3 data groups with results that were constructed from the biological development stages of the B-lymphocytes. The category A, the data set corresponding to the result only with stem cell. The first phase of development, i.e., the cellular phase that has the potential to differentiate into any other cell type. The cells at this stage are the cells potentially chosen for the possible treatments of diseases; category B, the data corresponding only to the result with pre-B cells, that is, in the differentiation process already compromised with the B-lymphocyte lineage; and category C, only the data corresponding to the result with fully differentiated B cells, I.e., cells already fully committed to a cell line. The student groups were not informed about which category they were handed to solve. The research was based on the situation problem that a researcher needed to treat experimentally a group of mice with a chronic disease with stem cells extracted from another healthy mouse. However, before treatment the students needed to check which of the samples had only undifferentiated cells. The analysis of the data provided support for the groups of students with information to conclude at which stage the cells are in the sample that were analyzed. We can classify the proposed investigative activity in level 1 structuring according to Smithenry (2010) and adaptations by Blanchard et al. (2010), i.e., problem/question situation, methods, data provided by the teacher and interpreting the results by students.

For the recording of data generated by the students during the execution of the inquiry-based learning activity, an instrument called 'laboratory notebook' was designed, based on the structure of Stephen Toulmin's framework argument (Toulmin, 1958). The author proposes in his book 'The Uses of Argument' (1958) that discussions are constituted by the elements of a layout basically composed of Data (the structure that holds the facts, the empirical data, involved in the argument that support); Justification (the structure formed by the rules, principles, theoretical knowledge, and reasons to justify the connection between the data found, constructed and/or analyzed and the conclusion defended) and Conclusion (the structure that includes the statement whose merit is being established and defended) (Manzoni-de-Almeida et al. 2016; Manzoni-de-Almeida and Trivelato, 2015). Therefore, the execution of the inquiry-based learning activity was divided into three parts: i) the teacher to investigate the presentation of the problem situation and the question (duration of approximately 20 minutes); ii) the moment that the groups of students analyze the set of experimental data (duration of 90 minutes); iii) and the final third part comprises a discussion, along with the groups, about the results found by each group (approximately 20 minutes duration).

Data analysis

Data were collected and analyzed in two ways. The first one consisted of the audio recording of the dialogues of the students in a group when they performed the investigative activity for analysis of the categories of epistemic operations based on synthesis of Jimenez-Aleixandre, Bugallo and Duschl (2000) and Silva and Mortimer (2013), mobilized by the groups of students. The second was the analysis of the epistemic status, according to Kelly & Takao (2002), present in the written contents of immunology in the laboratory notebooks of the student groups. The research participants, who read and signed the Free Consent Term (TLC), previously allowed all the information collected. The present study was submitted, analyzed and allowed for accomplishment by the ethics committee.

The audio recordings of the groups of students, with 90 minutes' duration per group. Each of these moments contained between 7-10 minutes. The sections selected for analysis were transcribed. The analyses of the transcripts of the speeches of the student groups were carried out by separating and analyzing the statements according to the map of analysis of verbal interactions between students-students and teacher-students in the science classes proposed by synthesis of Jimenez-Aleixandre et al. (2000) and Silva and Mortimer (2013). The transcriptions were analyzed and classified in the set of epistemic operations categories. The proposed categories were: Definition (when the student accomplished the definition about something, object or phenomenon); Generalization (when a generalization of the theme was made); Explanation (when the movement of explanation of something was accomplished); Description (when the student described some procedure or phenomenon); Classification (when the student performed the classification of some object, some phenomenon or knowledge); Exemplification (when the student mobilized examples of immunology or other areas of knowledge, in his speech); Comparison (when the student compared objects, theories, situations or knowledge); Analogy (when the student used the analogy to exemplify or explain something); Calculation (when any calculation or numerical operation was performed).

For the analysis of the epistemic status of the reports written in the "laboratory notebook" by the groups of students, we adapted the proposals synthesized and inspired by Kelly and Takao (2002) and Silva (2015) to our situation. These authors present an extensive set of writings in the analyzed reports of the students, such as methodological situations, data production, justifications and conclusions, which allowed a further categorization of the epistemic status of propositions. Here, for our analysis, we performed adaptations where the "laboratory notebooks" were individually analyzed and considered as a single argument each, since we were only working with previously structured reports in the basic form of data description, justifications and conclusions as proposed in the structure of Toulmin. The analysis was performed by type of question built on the notebooks based on the Toulmin argumentation structure present in the laboratory notebooks as previously described: description and presentation of the data, justification and conclusion of the analysis. They classified the reports with the epistemic status based on the description of the epistemic practice articulated to the investigated content (differentiation and biology of B-lymphocytes). Therefore, the categories adapted to the proposed reports were: Epistemic status level I (when in the report the mention group refers explicitly to the experimental data provided, without describing them); Epistemic status level II (when in the report the group describes identifying data and characteristics of cellular differentiation); Epistemic status level III (when in the report the group describes, appoints and explains: identifying and referring to data, and using theoretical model or concepts of immunology [particularly on the biology and gene recombination of antibody production in B-lymphocytes, example, mobilizing concepts of protein synthesis] to explain the data provided or results found).

Results

In the survey on the experience of students in the scientific profession, the survey carried out showed that 25% carried out a scientific initiation internship and that only 1% of those were included in Immunology. The others, who underwent a scientific initiation internship (5%), were related to areas close to immunology, for example, biochemistry, cellular and molecular biology (data not show). This data set suggests the profile of the inclusion in the scientific universe of the students of biological sciences belonging to this class.

Of the 12 groups of undergraduate students, only one did not reach the expected conclusion of the activity, i.e., they did not discover from the data provided what stage of development. In order to analyze the reports completed by the student groups, we use the theoretical basis of the proposed epistemic status (Silva, 2015 [adapted from Kelly and Takao, 2002]) to analyze the reports completed by the students regarding the epistemic status and test the conceptual formulation of written propositions developed by undergraduate student groups. The results of the analysis of the reports (Figure 1) showed that of the 12 reports completed by the twelve groups of students, 1 report had epistemic status I, 3 had epistemic status II and 8 reports with epistemic status III. Interestingly, the eight reports that presented the epistemic status III are related to situation 1 and 3 of the activity, i.e. the analysis and conclusion of the activity for the undifferentiated and differentiated cells in B cells, respectively. The three reports classified in status II and the only one categorized in status I (which the group of students could not conclude) are from situation 2, that is, the cells at an intermediate moment of differentiation, the pre-B cells. Taken together, these data suggest a multiplicity of epistemic statuses in the fulfillment of propositions in the formulation of the analyzes, justifications and conclusions of the argument coming from the analysis of the data.

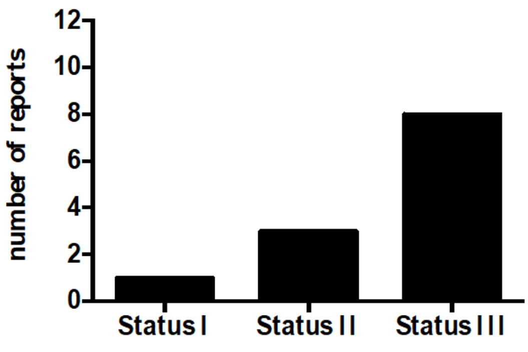

Figure 1.- Analysis of the epistemic status in the reports. Status I= identifies and describes the results. Status II= makes explicit reference to the results. Status III= describes and explains the results.

To investigate the predominant epistemic operations in the interactions between the students of the groups in solving questions with qualitative and quantitative experimental data in the construction of knowledge in the investigative activity, we adopted the categories of the theoretical reference of Silva and Mortimer that offers us a category for this analysis in oral discourse data. For this analysis, we take the transcriptions of two situations in each group. As an example of quantitative question, we took the analyses of the transcripts of the speeches between the students in resolving exercise 1 - analysis of the RAG gene expression values by PCR - and resolving the exercise 4 - analysis of the samples of northern blot for the expression of the MRNA of genetic fragments for the genetic recombination for formation of antibody molecule. The results of the students' speeches in the selected groups in the analysis of the epistemic operations we noticed the differential appearance of the epistemic operations between resolving the questions of "Qualitative" and "Quantitative" nature (Figure 2).

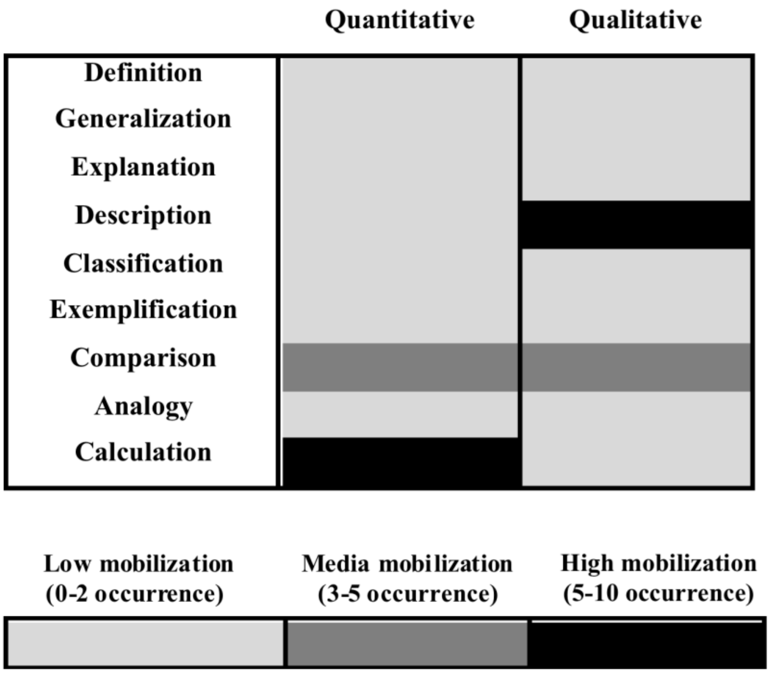

Figure 2.- Profile of the mobilization of epistemic operations by a group of students during the execution of a research activity in immunology in higher education.

In general, for both the "Quantitative" and "Qualitative" questions, there was a predominance of the epistemic operation of calculation, comparison, description and generalization in both classes. On the other hand, the distribution of the appearance of these epistemic operations in the speech of the students in resolving these questions presented a qualitative difference. We note that the groups, for resolving the "Quantitative" question, mobilized predominantly the epistemic operation of calculation when compared to the mobilization for the question of "Qualitative" nature. We note that for the resolution of the "Qualitative" question, the students mobilized the epistemic operation of description in detriment of other operations, as for example the calculation as we noted for question 1 of a "Quantitative" nature 5). These data suggest coherence with the proposal of the command of the questions, since the statements of the commands of the questions required description of the data shown. One question required, before the conclusion of the results, a mathematical epistemic process. However, another question, an epistemic process of observation and interpretation of images.

Discussion and conclusions

Science teaching in higher education gains some characteristics in relation to basic science education. For example, while at the level of basic education the aim is linked to the insertion of the subject the skills and abilities of the universe and scientific language, scientific teaching in higher education is also added to the goal for the direct development of skills and abilities for professional training, whether in the scientific field or in the technical exercise of the profession (which does not rule out the use of logical scientific thinking), in the development of skills for the actual exercise of a profession at a technical level, scientific or technical/scientific. On this development for the practice of the profession in the scientific scope, the area of Immunology, within the biological sciences, in the twentieth century was one of the most prominent areas, in the scientific development and training of researchers in Biology. In the scientific aspect the leap in development was because of great importance to the studies to clarify infections, for example, of HIV, Zika, dengue and Ebola virus and for the vaccines against microorganisms in general; besides studies related to tumors, autoimmune diseases and hypersensitivities. These advances led to a parallel incentive for the development of researchers in the area, abroad (Hannum, Kurt and Walser-Kuntz, 2016) and in Brazil, as suggested by Barral and Barral-Neto (2007), Rumjanek and Leta (1996) and Dos Santos and Rumjanec (2001), which showed that Brazil occupies the seventeenth place in scientific production, while the production of Brazilian Immunology ranks eleventh, accounting for 12.4% of all the most cited Brazilian scientists in all areas, 9% of total biomedical production. This scenario shows that there is an interest in the formation of scientists focused on the study of Immunology. Thus, the challenge is in the engagement and specific scientific training for immunology still in the higher education classes of biological and medical courses. In view of these challenges, in the last few years we have developed a didactic inquiry-based learning activity in immunology that has served as a model for the study of several aspects of the dynamics involved in the immunology classroom of higher education. Here, our results using this immunological research activity show that the execution of the didactic sequence in the immunology course has mobilized important skills and epistemic operations for resolving qualitative and quantitative data of classic immunology experiments.

Inquiry-based learning education in a complex course such as Immunology can make it possible to aid in scientific training, focusing on the training of scientists, higher education and opening up possibilities and engaging for this scientific development, often allowing the insertion of many students in the scientific universe, since the example in our case study here, few students were performing internship in scientific initiation in the scientific areas, especially of Immunology. The reasons for not completing the scientific initiation internship can range from the actual non-awakening to scientific activity to the lack of opportunity in a laboratory. This reasoning should not lead one to think that research teaching can propose the substitution of deep training in the development of a scientific project at an internship of scientific initiation; however, the student can engage and mobilize important scientific skills, even performing a project of research in the classroom. Besides providing opportunities for students who are not completing the internship in science, in this case, in particular immunology and its specificities. Already, in this line of thought, our results showed this possibility. The set of analyses of the group writings in the student reports in the execution of the inquiry-based learning activity showed a diversity of so-called 'epistemic status' (Kelly and Takao, 2002). The vast majority of the reports written by the groups are framed at levels II and III of 'epistemic status' which require the description and explanation of the data provided for analysis in the research with theories and models within the field of knowledge of immunology explained in the previous classes of the didactic sequence (classes before) such as principle of the techniques used to get data on immunology and knowledge about the development of B-lymphocytes pointed out in previous classes. This result is important because it provides the visualization of the correlation between raw scientific data given and analyzed by student groups with their meaning in models and theories in immunology.

An important point is that the routing of many student groups to produce reports with citations, descriptions and explanations are the cognitive operations (Jiménez-Aleixandre et al., 2000; Silva and Mortimer, 2013) mobilized in student group interactions when carrying out the inquiry-based learning activity in immunology. The production of knowledge in Immunology uses several laboratory techniques that can provide a qualitative analysis, i.e., visual gene bands or phenotypic changes observable by the 'naked eye'; can provide a quantitative analysis, based on mathematical quantification of cells or molecules. We designed our activity in such a way as to provide the students with these two experiences of data analysis in Immunology, and with this perspective we analyze the moments of execution of the investigative activity in these two moments. Here, the PCR technique is taken as the quantitative technique, considering that, for interpreting the data and getting results, the researcher or student uses the numerical values obtained from the amplification of molecules of genetic material; and Northern blot as the qualitative technique, because with this technique the researcher or student can get an interpretation of results by observing by 'naked eye' the 'bands' corresponding to pieces of the genetic material expressed in a polyacrylamide gel and, subsequently, a membrane of cellulose. In this way, both techniques obey the categories already explained on qualitative and quantitative techniques. The analyses of the results showed that the groups of students, when analyzing and solving quantitative data, mobilized more of the epistemic operation of calculation in relation to the other proposed epistemic operations. However, in performing the qualitative data, the groups of students showed greater mobilization of the epistemic operation description in relation to the other epistemic operations listed. In both situations, the groups also mobilized in a similar way the epistemic operation of comparison. This group of results suggests that the proposed inquiry-based learning activity induced in groups of students the mobilization of specific epistemic operations for the aim resolution of the data proposed in each of the techniques, thus, resulting in the solution of the research situation.

In conclusion, we believe we can associate the encouragement and training of higher education students for the scientific career in immunology with specific methodologies that allow the mobilization of important, fundamental epistemic operations in the development of immunology research. This set of objectives can be part of a new proposal in the specific field of immunology didactics, on the teaching of science simply, with low cost and accessible to the diverse students, professors and universities of the world. Our results suggest the potential of this strategy in bringing the university's classroom closer to conceptions of a real border space between the production of scientific knowledge by the scientist and the teaching of science.

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References

Anderson, R. (2002). Reforming Science Teaching: What Research says about Inquiry. *Journal of Science Teacher Education*, *13*(1), 1-12. Recovered from http://www.jstor.org/stable/43156282. doi: https://doi.org/10.1023/A:1015171124982

Abbas, A. K., Lichtman, A. H., & Pillai, S. (2008). Imunologia Celular E Molecular: Elsevier.

Barral, A., and Barral-Netto, M. (2007). Uma breve perspectiva da Imunologia no Brasil e na Bahia. *Gazeta médica da Bahia*, *77* (2), 241-244. Recovered from https://www.arca.fiocruz.br/handle/icict/10904

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., and Granger, E. M. (2010). Is inquiry possible in light of accountability? A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education*, *94*(4), 577–616. doi: 10.1002/sce.20390

Calich, V., Vaz, C. (2009) Imunologia. Rio de Janeiro: Editora Revinter.

Cunningham, C. M., and Kelly, G. J. (2017). Epistemic Practices of Engineering for Education. *Science Education*, *101*(3) 486–505. doi: https://doi.org/10.1002/sce.21271

Dos Santos, N. F., and Rumjanek, V.M. (2001). Brazilian immunology: One hundred years later. *Scientometrics*, *50*(3), 405-418. doi: https://doi.org/10.1023/A:1010502513971

Duschl, R. A. and Bismarck, A. S. (2016). *Reconceptualizing STEM education: the central role of practices*. New York, NY: Routledge, Taylor & Francis Group.

Hannum, L., Kurt, R. A., and Walser-Kuntz, D. R. (2016) Developing Immunologists: A Role for Undergraduate Education. *Trends in Immunology*, *37*(7), 425-6. doi: https://doi.org/10.1016/j.it.2016.03.008

Jiménez-Aleixandre, M. P., Bugallo, A., and Duschl, R. A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science. Education*, *84*(6) 757–792. doi: 10.1002/1098-237X(200011)84:6<757::AID-SCE5>3.0.CO;2-F

Kelly, G. J., Chen, C., and Prothero, W. (2000). The epistemological framing of a discipline: Writing science in university oceanography. *Journal of Research in Science Teaching*, *37*(7), 691–718. doi: https://doi.org/10.1002/1098-2736(200009)37:7%3C691::AID-TEA5%3E3.0.CO;2-G

Kelly, G., and Duschl, R. A. (2002). Toward a research agenda for epistemological studies in science education. *Annual meeting of the National association for research in Science Education*, Nova Orleans, Louisiana, EUA

Kelly, G. J., and Takao, A. (2002). Epistemic levels in argument: An analysis of university oceanography students' use of evidence in writing. *Science Education*, *86*(3), 314–342. doi:10.1002/sce.10024

Kelly, G. J., and Licona, P. (2018). Epistemic practices and science education. In M. Matthews (Ed.), *History, philosophy and science teaching: New research perspectives* (pp. 139-165). Springer: Dordrecht.

Latour, B., and Woolgar, S. (1986). *Laboratory Life: The Construction of Scientific Facts*. Princeton: Princeton University Press

Manzoni-de-Almeida, D., and Trivelatto, S. (2015). Elaboração de uma atividade de ensino por investigação sobre o desenvolvimento de linfócitos b. *X Encontro Nacional de Pesquisa em Educação em Ciências*. X ENPEC, 2016, Aguas de Lindóia

Manzoni-de-Almeida, D. (2016). O desenvolvimento da escrita argumentativa nas aulas de imunologia do ensino superior por metodologias ativas. Compartilhe Docência, 1(2), 3-19.

Manzoni-de-Almeida, D., Marzin-Janvier, P., and Trivelato, S. L. F. (2016). Analysis of epistemic practices in reports of higher education students groups in carrying out the inquiry-based activity of immunology. *Investigações em Ensino de Ciências*, *21*(2), 105-120. doi: http://dx.doi.org/10.22600/1518-8795.ienci2016v21n2p105

Mello, P. S. (2019). O papel de uma atividade de ensino por investigação de imunologia nas aulas de cursos das áreas de ciências biológicas e da saúde. (Doutrado), Universidade Federal de Minas Gerais, Belo Horizonte. Retrieved from http://hdl.handle.net/1843/32301

Minner, D. D., Levy, A. J., and Century, J. (2010). Inquiry-based science instruction – what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching.* 47, 474–496. doi: https://doi.org/10.1002/tea.20347

Natale, C. C., Pereira, M. G., Mello, P. S., & Manzoni-de-Almeida, D. (2019). Tendências de pesquisas sobre o ensino de imunologia no brasil: uma análise de conteúdo dos resumos do Congresso da Sociedade Brasileira de Imunologia de 2010 a 2017. Perspectivas de la Comunicación, 12(1), 7-23.

Park Rogers, M. A., and Abell, S. K. (2008), The design, enactment, and experience of inquiry-based instruction in undergraduate science education: A case study. *Science. Education*, *92*(4), 591–607. doi: https://doi.org/10.1002/sce.20247

Rumjanek, V. M., and Leta, J. (1996). An evaluation of immunology in Brazil (1981-1993). *Brazilian Journal of Medical and Biological Research*, *29*(8), 923-31. Recovered from https://www.semanticscholar.org/paper/An-evaluation-of-immunology-in-Brazil-1981-1993-Rumjanek-Leta/1e3c3fa7fe55abba2acda1ae91b65c2083737df4?tab=citations

Sasseron, L. H. (2015). Alfabetização científica, ensino por investigação e argumentação: relações entre ciências da natureza e escola. *Ensaio Pesquisa em Educação em Ciências*, *17*(spe), 49-67. doi: http://dx.doi.org/10.1590/1983-2117201517s04

Seixas Mello, P., Cotta Natale, C., Marzin-Janvier, P., Vieira, L. Q., & Manzoni-de-Almeida, D. (2021). Inquiry-based learning in immunology: analysis of scientific argument construction by undergraduate students in biological science and health care classes. Journal of Biological Education, 1-15. doi: 10.1080/00219266.2021.1877778

Silva, A. C. T., and Mortimer, E. F. (2013). Contrastando professores de estilos diferentes: Uma análise das estratégias enunciativas desenvolvidas em salas de aulas de Química. *Revista Electrónica de Enseñanza de las Ciencias*, *12*(3), 524-552. Recuperado de http://reec.educacioneditora.net/

Silva, M. B. (2015). *A construção de inscrições e seu uso no processo argumentativo em uma atividade investigativa de biologia* (Tese de Doutorado). Universidade de São Paulo, São Paulo.

Smithenry, D. W. (2010). Integrating Guided Inquiry into a Traditional Chemistry Curricular Framework. *International Journal of Science Education*, *32*(13), 1689-1714. doi: https://doi.org/10.1080/09500690903150617

Toulmin, S. (1958). *The uses of argument*. Cambridge, U.K: Cambridge University Press