Article

Virtual Immunology: Software for Teaching Basic Immunology

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Abstract

As immunology continues to evolve, many educational methods have found difficulty in conveying the degree of complexity inherent in its basic principles. Today, the teaching–learning process in such areas has been improved with tools such as educational software. This article introduces "Virtual Immunology," a software program available free of charge in Portuguese and English, which can be used by teachers and students in physiology, immunology, and cellular biology classes. We discuss the development of the initial two modules: "Organs and Lymphoid Tissues" and "Inflammation" and the use of interactive activities to provide microscopic and macroscopic understanding in immunology. Students, both graduate and undergraduate, were questioned along with university level professors about the quality of the software and intuitiveness of use, facility of navigation, and aesthetic organization using a Likert scale. An overwhelmingly satisfactory result was obtained with both students and immunology teachers. Programs such as "Virtual Immunology" are offering more interactive, multimedia approaches to complex scientific principles that increase student motivation, interest, and comprehension.

Keywords: *immunology; cellular biology; software; teaching*

Introduction

The phenomena that drive cellular and biochemical responses are often complex and are often challenging concepts in educational settings [1]. In the field of immunology, the level of complexity continues to increase as we begin to discover the several highly regulated cellular and molecular circuits in the immune system. Thus, the learning of many essential concepts depends on the students' ability to visualize and create mental models that support scientific comprehension, particularly at the molecular level [2, 3]. Fortunately, the information and communication technologies (ICTs) have allowed several advances in current educational practices that aid the integration of this information into knowledge.

Computers and media have revolutionized education by searching for new, more interactive methodologies in the teaching–learning process. The Internet has played no small part in that union by providing innovative experiences and pedagogical activities online [4]. Educational software and graphic visualization tools, such as molecular modeling and graphic animations, have been successful in generating dynamic representations of information that have often been difficult to understand when presented solely in text [5]. Several studies have found that educational software facilitates the learning of specific concepts at the cellular and molecular levels in the biological and health sciences [6–8].

While still in its early stages, the refinement of such programs may eventually be able to reduce or avoid the use of animals in experimental immunology classes. As there is a close theory–practice relationship, which is fundamental to the quality of immunology classes for the students' practical experiences, allowing them to be more critical and engaged in regard to theory [9], it remains difficult still to eliminate the use of live animals in laboratory classes. While in certain cases educational software might have substituted animals without any loss of learning—clearly, we are still distant from software programs that can accurately replicate or substitute laboratory classes. Therefore it is important to consider that in several countries and regions on the planet who are unable to provide students with such practical experience and a global trend

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toward animal protection, there is mounting evidence that in several cases animal replacement in experimentation classes could be possible, and as such an ethical responsibility to work toward such educational advancements. As well, clearly the development and assessment of new techniques are important steps for a new direction of teaching and instruments that will facilitate student learning [10]. This is not to say, that this is novel, as with the advent of information technology, the availability of resources and cognitive tools has significantly increased [11] and students are exposed, some say over-exposed, to a vast array of learning tools and technology, such as animated modeling and educational software. As such, the way learners interact with resources is changing qualitatively and the success of their learning is increasingly dependent on how and which of these resources are utilized [12] for particular subject areas.

This article presents the development of an educational software program that aids in the teaching of immunology and related subjects to the technical school level or even undergraduate and graduate levels students. This article qualitatively evaluates the software experience of the students and teachers with regard to its ease of use, clarity of ideas, and if the user considered it to be a benefit to the learning experience for the area of immunology.

Materials and Methods

There are several methodologies for the development of educational software, such as those presented by Johnson [13], Vaughan [14], Oliveira *et al.* [15], Bassani *et al.* [16], and Costa [17]. All of these methodologies include similar stages, although with different names and emphases. Based on the references cited above, the modules of the structured methodology utilized for our program consisted of: (1) choice of content; (2) planning; (3) design/prototype; (4) evaluation; (5) validation and distribution.

Choice of Contents

The themes "Organs and Lymphoid Tissues" and "Inflammation" were chosen as they are topics commonly presented in the initial part of most textbook of Immunology. Based on our experience as teachers, these are typical areas that students have difficulty in. Inflammation, in particular is considered a difficult topic which is handled by at least three different disciplines: Immunology, Pharmacology, and Pathology.

Planning

Module: Organs and Lymphoid Tissues

Lymphoid organs, including bone marrow, thymus, spleen, lymph nodes, and other peripheral lymphoid tissues are central components of the mammalian immune system with essential roles in the immune response and the defense mechanisms against infectious agents. Briefly, they participate in three fundamental processes. First, lymphoid organs function as stromal niches for the development of lymphoid cells. Second, they control a sequence of events that ensure the generation of self-tolerant repertoires and antigenic receptors. Third, these organs play a role in regulating the efficiency and accuracy of the immune response, which ultimately depends on how organs and various types of lymphoid cells interact [18].

Our first module, "Organs and Lymphoid Tissues," begins with a virtual laboratory exercise in which an injection of India ink (representing the antigen) is injected by one of two routes: intradermal or intravenous. The two administration routes allow the user to observe the specific tissues and organs that are affected by each route and to learn about the specifics of each route.

Interactive animations were developed to allow the user to manipulate events using a computer mouse. The user applies anesthetics and India ink, with all steps accompanied by explanatory audio and subtitles. The interface consists of navigation buttons that allow the user to control the animation and an additional button linking to concepts that are related to the theme of "Organs and Lymphoid Tissues." Concepts, images, and photomicrograph icons were inserted that relate to the theme. The icons direct the user to pages containing additional written information about specific characteristics of each organ.

There is a laboratory area included in the software, which contains instruments (i.e. forceps, syringe, scissors, pins, and Petri dishes) and anesthetics to simulate real laboratory practice as closely as possible.

The second activity of the module presents an anesthetized mouse dissection in which the removal and manipulation of organs and lymphoid tissues is simulated. In order to facilitate learning, the computer cursor allows users to manipulate the virtual instruments (Fig. 1).

In summary, the animation presents a real situation in which students can observe the events following entry of an antigen into an organism, including the organism's defense mechanisms in response to contact with this antigen and the possibility of interaction in the different stages.

Module: Inflammation

Inflammation is one of the most complex events of the immune response, given the variety of cell types and molecular interactions involved in the chain of events that follows a pathogenic stimulus or tissue injury [19]. This module presents an acute inflammatory response, which is a relevant theme in immunology, physiology, pharmacology, pathology, and many other health-related areas.

The inflammation module animates the events following a pathogenic stimulus and the local alterations that are found. The development of this set of animations was based on a hypothetical situation in which an individual is exposed to a contaminated needle (i.e. containing bacteria) and a sterile needle (Fig. 2). The goal is to introduce the cell types involved in the inflammatory process and to provide a visual

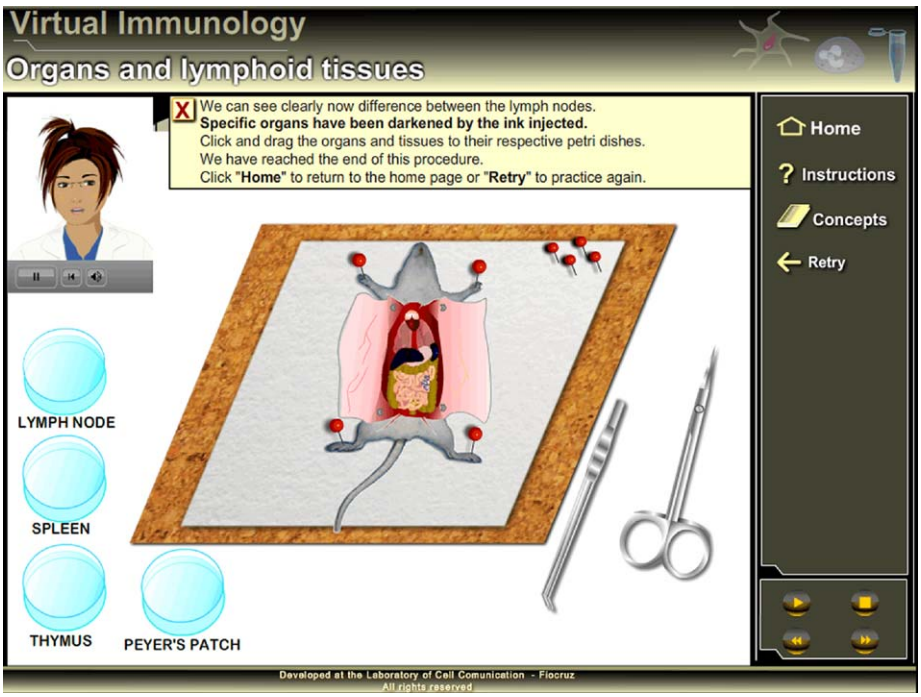

FIG 1 At this stage, students can choose to conduct a mouse dissection after applying the ink through one of the administration routes. They have the ability to view and remove organs and lymphoid tissues to the Petri dishes (located in the left corner of the screen in blue).

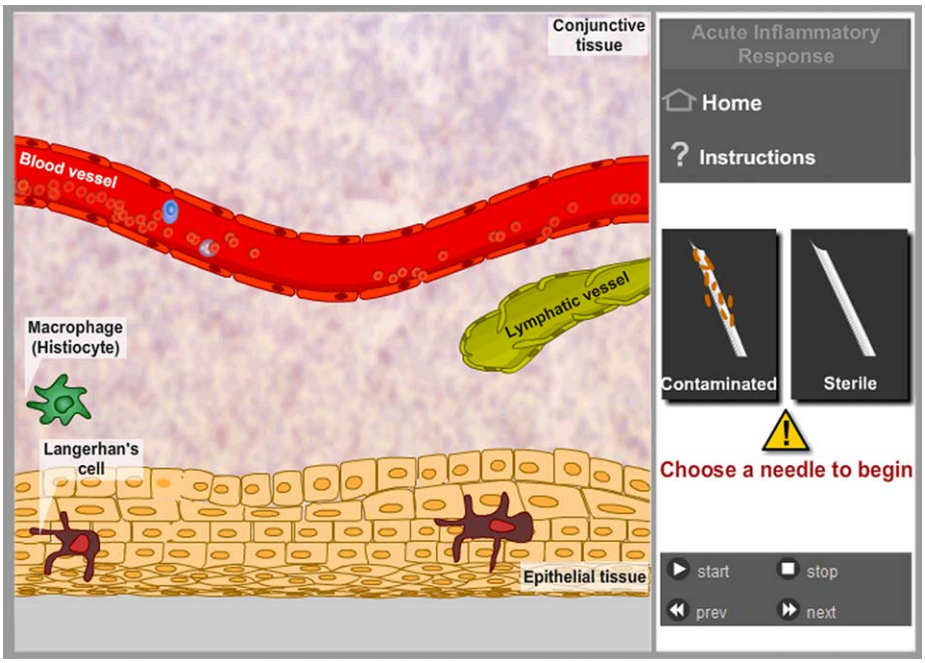

FIG 2 Screen of the "Inflammation" module. On the right side, there are options to insert a contaminated or sterile needle into the tissue and to observe the subsequent events. As in the Lymphoid Organs module, navigation buttons are available to control the scenes.

experience of the interactions within the inflammatory phase. This module is divided into three stages: inflammation, cell transmigration, and phagocytosis.

The user has the option to choose one of the needles and then to observe the immunologic response. An important item described in this step and rarely addressed in

textbooks is the Hageman factor activation process (factor XII), which triggers a series of molecules involved in the inflammatory process.

To represent a phagocytic event, an animated sequence within the inflammatory response environment was developed to show the damage caused by the needle chosen in the previous scenario. Phagocytosis is an important mechanism with regard to innate immunity. Most of the phagocytic events are performed by specialized cells, such as blood monocytes, neutrophils, and tissue macrophages [20]. The animation of phagocytosis of a bacterium shows organelles and molecules that participate in this recognition process.

During cellular transmigration, a portion of the cellular adhesion, activation, and migration of participating molecules are highlighted. To facilitate understanding of this subject, legends were inserted to accompany the events, in order to explain each step of the inflammatory response. The animation presents the stages of cellular transmigration of neutrophils to the inflammatory site after tissue damage. We have also animated the interactions among molecules, cells, and tissues that are present in the transmigration process.

Software Development Tools

Modules were developed using a series of image-editing software, illustrations, and animations. Adobe® Flash® CS4 Professional and InkScape were central tools to the development of this project.

Software Evaluation

Evaluation of Perceptions of Software Quality

A modified version of Sander's methodology [21] was used to evaluate the users' perceptions of the quality of the software. Users completed a questionnaire composed of 14 affirmative statements with answers in the form of a Likert-type rating scale to evaluate the students' perception involving learning characteristics and the usefulness of the software as a pedagogical tool. Additionally, some questions involving the usability of the software were also collected. The students were requested to strongly agree, agree, neither agree nor disagree, disagree or strongly disagree with the statements presented regarding the above mentioned characteristics.

Furthermore, we had seven teachers from different Universities in Rio de Janeiro, who had more than five years of experience in teaching immunology to undergraduate courses, to evaluate the software, and complete the same questionnaire that was administered to the students.

A request for pointed criticism and suggestions for improvement of the software were made to the students and teachers alike.

All participants of this study were voluntary and signed the Free Informed Consent. The two groups that used the software then had 2 hr to navigate the inflammation and the lymphoid organs modules of the software via the web. During which, a tutor was present to answer questions from students about the handling of the software and to assure that students did not go to other sites. However, the tutor did not clarify doubts on the topics of immunology and each student worked individually on a computer using the software.

Results

The Likert-scale evaluations are presented in Fig. 3 and Table 1. Undergraduate students, in general, found the software to be of high quality and beneficial to the learning experience, as indicated in Fig. 3. Clarity of the biological concepts presented and ease of use of the program similarly were scored high on the Likert scale evaluation. Similar experiences were reported by the graduate students and teachers. There were a common profile among the groups (graduate students, undergraduate students, and teachers (Table1)).

User feedback—Graduate Student Comments

Comments from the graduate level students were closely considered as their level of understanding of these immunological concepts should be more in-depth than that of the undergraduate students. Sample comments are listed below.

Positive Feedback:	*Suggestions:*
User 01 *"If this software were available, I would use it with my high school students"*.	User 07 *"I wish it could have sound in the inflammation section"*
User 02 *"I really liked this type of tool. It helps to better visualize immunological processes."*	User 11 *"It should be left clearer when an animation is finished"*
User 18 *"The events of inflammation became clearer with the help of animation"*	User 16 "*I really liked the software, but there was a time when the mouse cursor" disappeared "and I had to restart the program."*
User 22 *"I did understand the chemotatic factors."*	User 09 "*The software is very good, but it is important to think about high school students, who do not remember the organs and body parts. Captions could be added to help."*

Note: Since receiving feedback and suggestions on the evaluations, the site has included this as a permanent feature on the site.

Relevance of Content: Teacher's Comments

The seven teachers, who had more than five years of experience in teaching immunology, had similar experiences as reported by the students. The comments from the teachers corroborated much of the earlier reported data, though

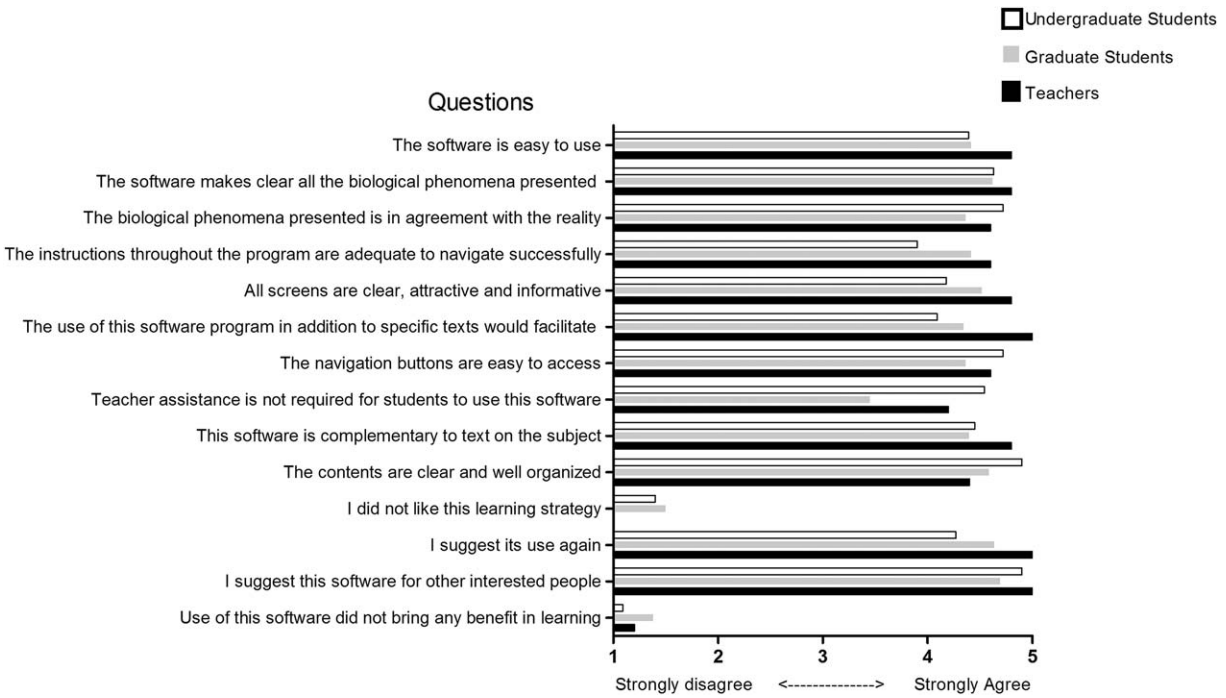

FIG 3 Likert-type rating scale to evaluate the students' and teachers' perceptions involving the characteristics and the usefulness of the software as a pedagogical tool. Abbreviations: SA = strongly agree; A = agree; AD = neither agree nor disagree, D = disagree and SD = strongly disagree.

help illustrate aspects of the perceived interdisciplinarity of the program and the target audience for the tool.

Teacher's Comments:

"The content covered in the modules is excellent. Mainly, because it is the initial approach in understanding the immune response."

"The concepts of immunology software are clear and updated."

"Some concepts need to be better explained and some events presented require more detail. However, the software is very good!"

"The software combines several basic areas of biology such as cell biology, biochemistry, physiology, beyond specific disciplines such as immunology and pathology."

"The software can also be used for high-school and would be a great tool for high-school students who are attending immunology laboratories."

Discussion

The development of multi-media tools to aid in complex subjects is by no means a new concept; however the ever-changing landscape of science education continues to bring forth new and challenging tasks for them to reach today's students. Within an era of changing educational paradigms with the advent of technological advances such as the Internet and the overwhelming amount of information available to students for tools to help contextualize complex topics and bridge these processes to the research and laboratory practices in their corresponding fields [22].

"Virtual Immunology" has been primarily developed in hopes to offer an animated simulation of complex processes that are often presented as static scenarios [6, 23, 24] when in fact their dynamic nature is often lost due to the complexity of the subject. The module offers a linear-temporal based simulation that has the capability but not the requirement of exploring more deeply certain processes or concepts by its optional "magnifying processes," utilizing the same concept as hyperlinks but in a media format. The module we believe aptly captures a vast amount of information allowing for the contextualization of several immunological principles and the presentation of parallel scenarios (sterile needle versus contaminated needle). Likewise, the "Virtual laboratory" module is meant to offer another dimension bringing together laboratory experience and procedures in an online interactive format to the concepts of immunological research, albeit at a very basic level. This module in particular we believe is a key component that is missing in courses that do not have a laboratory course accompanying the teaching of immunology, such as most online courses and distant learning. These two educational scenarios continue to evolve attempting to utilize multi-media tools to create more comprehensive educational experiences

TABLE 1 ***Results of clarity and usability of the software reported by teachers, undergraduate and graduate students.***

	Teachers		*Graduate students*		*Undergraduate students*	
Questions	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Use of this software did not bring any benefit in learning	1,2	0,4472	1,38	0,6965	1,09	0,9244
I suggest this software for other interested people	5	0	4,69	0,5984	4,9	0,5045
I suggest its use again	5	0	4,64	0,6933	4,27	0,4671
I did not like this learning strategy	1	0	1,5	1,064	1,54	0,3015
The contents are clear and well organized	4,4	0,5477	4,59	0,5934	4,9	0,603
This software is complementary to text on the subject	4,8	0,4472	4,4	0,8774	4,45	0,7006
Teacher assistance is not required for students to use this software	4,2	0,8367	3,45	1,231	4,54	0,4671
The navigation buttons are easy to access	4,6	0,5477	4,36	0,6675	4,72	0,6876
The use of this software program in addition to specific texts would facilitate learning		0	4,35	0,8492	4,09	0,8202
All screens are clear, attractive and informative	4,8	0,4472	4,52	0,5995	4,18	0,3015
The instructions throughout the program are adequate to navigate successfully	4,6	0,5477	4,41	0,6763	3,9	0,7006
The biological phenomena presented is in agreement with the reality	4,6	0,5477	4,36	0,8314	4,72	0,6876
The software makes clear the biological phenomena presented	4,8	0,4472	4,62	0,5241	4,63	0,3015
The software is easy to use	4,8	0,4472	4,41	0,7017	4,39	0,3015

Note. *Teachers (N = 7) Graduate students (n = 58) Undergraduate students (n = 11) Items were rated on a 5 point Likert scale (1=strongly disagree, 5 = Strongly agree).*

SD = Standard deviation

that offer more interaction and engaging components to counteract some of the inherent difficulties of engagement associated with online learning. Finally, another important factor that can be gained through the use of the software is a simulation of an *in vivo* experiment. The academic reliability of a virtual laboratory will clearly require further study and refinement of these practices to truly attempt to achieve a real laboratory practice. The reality is that the practical use of animals is infeasible in many educational settings, but beyond of these physical practicalities there is the ethical obligation to continue in the pursuit of a more humane practice of science and the teaching of it. This virtual environment allows students to feel comfortable in repeating the practice of medical procedures as often as necessary to improve their learning [10].

While "blended learning" or the use of multimedia tools in combination with other formats of teaching is by no means a new concept, it has yet to be effectively realized in many of the classrooms today. Immunology remains as a complex area that has been proposed as likely to benefit from the combining of text, animation, video, and simulation, to facilitate the understanding of immunological concepts [25]. According to students' answers, "Virtual Immunology" would improve learning when associated with specific reading from the topic literature. Moreover, we also had positive reviews of this software program in its ability to present immunological concepts. In general, there was an overwhelming favorable response to the software in all aspects, by both teachers and students (Fig. 3 and Table 1). This is supported by other studies which have demonstrated that

using multimedia resources, such as computer dynamic simulations and educational software, that have been very successfully applied in the teaching–learning process and increases interest and improving the understanding of concepts, related to areas such as genetics, biochemistry, molecular biology, and immunology [26–29]. Thus, from the qualitative assessment of "Virtual Immunology," we are providing a good quality product for learning topics of immunology both in undergraduate and graduate courses. According to users' answers, most agreed that the program product interface was clear and attractive, and they had a favorable experience with the visual and organizational style.

Additionally, "Virtual Immunology" can be used to facilitate the integration of virtual learning environments in curricula and teaching methods in basic science and applied public-health practice [30]. While most of the immunology textbooks sold in Brazil, USA, and many other countries are accompanied by CD-ROMs containing simple animations [31], there is a movement toward cloud based applications that can effectively integrate into large learning management systems (LMS) [32–34]. "Virtual Immunology" is available free from http://www.lcc.kftox.com. Moreover, it is important to note that we aim to develop other modules to be incorporated in the software such as immune response, innate, and acquired immunity.

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