STAYING CURRENT

Open educational resources in immunology education

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Faggioni T, da Silva Ferreira NC, Lopes RM, Fidalgo-Neto AA, Cotta-de-Almeida V, Alves IA. Open educational resources in immunology education. Adv Physiol Educ 43: 103–109, 2019; doi: 10.1152/advan.00116.2018.—The use of computers as a pedagogical resource is currently on the rise. In the case of immunology, students present difficulties in visualizing molecular phenomena. Thus the use of animations and simulations available on the internet might facilitate the learning of complex immunological concepts. In this context, it is important to map and assess the currently available resources that may be used for educational purposes. This study comprises the search and analysis of educational immunology software freely available on the internet, which can aid students and health professionals in effective learning and continuing education scenarios. A detailed search in English on the existence of free software was carried out on websites and scientific databases. The results clearly indicate a lack of freely available and scientifically validated immunology educational software, despite the existence of several software programs that could be used as auxiliary teaching tools.

education; educational software; health professionals; health students; immunology; open educational resource

INTRODUCTION

Immunology is noted for its discoveries and direct contribution in disease prevention and treatment. It is no longer exclusively devoted to studying body responses to infectious agents, and has changed from a basic discipline to a far-reaching interdisciplinary science, with impacts on almost all health science areas. Moreover, the state of the art in this field indicates a broader and deeper nature of the knowledge produced in immunology research. The connections of the immune system with both the endocrine and the nervous systems, via the bidirectional interplay between cells and factors, associates a wide and organic view of the immune network in both physiological and pathological conditions. The high amount of data amassed from the intricate molecular networks within each immune cell and the dynamic networks of cell interactions throughout the body are of significant importance (40). In this context, knowledge on immunological events is frequently a challenging and complex task, considering both the effects of neuroendocrine factors on immune cells and how these cells operate to defend the host against infections and tumors.

Despite the contemporary need to take immunology classes as an earlier and in-depth subject during student training (15), education concerning immunological concepts is often poorly connected with current facts and student daily life. Students are also faced with other impeding learning factors, such as the novelty of most of immunology content being associated with minor knowledge previously acquired in basic education, a complex and specific language, the need for abstraction and a short curriculum period in undergraduate courses regarding immunology teaching (38).

The study of immunological phenomena is frequently carried out alongside a massive amount of information on cellular and molecular components, solely in the form of expository presentations of static images in a conventional teacher-centered manner (38). This approach can hinder learning and reduce student interest in the subject. This suggests the need for immunology teaching through new techniques, where students can be encouraged to change their passive learning routine. Furthermore, the teaching of complex immunological phenomena should apply different strategies and tools, to clearly integrate immunology with other disciplines, including cellular and molecular biology, biochemistry, physiology, chemistry, and mathematics, as well as distinct clinical fields.

In this context, technological resources, such as computers and access to the internet, display the potential to diversify educational activities and are useful to both evaluate and promote student ability in understanding complex concepts, in addition to developing motivation, collaborative skills, and critical thinking (43). Despite the “common sense” that information and communication technologies improve teaching and learning in several disciplines, no formal proof for this is available, as discussed in a published meta-analysis report (19). Nonetheless, most studies demonstrate that student motivation increases with the use of educational software (1, 2).

As expected, the internet has a clear influence on immunology education (8). Thus rich tools for learning immunology may be explored by employing information and communication technologies, including educational software. In fact, through interactive texts, graphs, animations, and simulations, these tools potentially expedite the teaching and learning of complex immunological events, aid in approaching clinical cases and classroom practices, and also allow for testing the effective learning of basic immunology concepts (13, 35).
Another important issue is that, by applying simulations, the use of animals in experimental immunology classes can be reduced, without loss of learning aims (8, 10). Currently, technology and education are offered in an inseparable relationship, as technology application is directly in line with the new proposals for high standard education. This reinforces the significant potential of computers in the process, particularly due to the use of hypermedia resources, which gather images, sounds, texts, and videos, and also allows for a nonlinear reading of the subject contents (12).

In this scenario, open educational resources (OER) may provide important information and communication sources aimed at immunology teaching and training. This term was recommended in a UNESCO (United Nations Educational, Scientific and Cultural Organization) forum, in 2002, and is defined as those educational resources freely available and open for educators, students, and the academic community, who may use them for teaching, learning, and research. It is important to emphasize the potential of software employed in teaching and learning processes among OERs (24). However, even in developed countries, the effective use of educational software is not apart of most student routines. In fact, only 12% of students actively use educational software, whereas over 50% use computers to send and receive e-mail, chat, search the internet, play games and edit texts (30). Therefore, the health sciences academic community, by pursuing trusted OERs as internet tools generated to dedicated immunology learning activities, will aid in strengthening the quality of these tools and profit from a higher level of education in this field.

METHODS

To identify the types of educational immunology resources available for free use on the internet, searches were carried out using general search engines like Google, Yahoo, Google Scholar, and Bing, as well as scientific databases, including PubMed, Web of Science, ERIC (Education Resources Information Center), and Scielo, on August 2018.

The electronic search was performed using the following key words (18, 36): “animation,” “app,” “application,” “educational software,” “educational tools,” “interactive,” “open educational resources,” “teaching,” “video,” “web,” and “websites.” To restrict the content search to immunology, the following words were used in combination with those presented above: “immunology,” “immune system,” “immunity,” and “immunobiology.” All searches were carried out in English.

At first, certain sites, such as YouTube, were observed as containing a high number of animations in the immunology area, but most do not identify if the tool was developed by specialized professionals belonging to the immunology field. Thus a selection criteria was defined, to evaluate sites developed by education or research institutions (or those that mention expert advice) that freely host immunology educational resources on the internet.

To use web resources as educational tools, it is expected that the content will be addressed in a simple and clear manner, especially for students (in this case, undergraduate students) who seek these websites to facilitate the learning of complex concepts. The tools should be attractive, containing colors, animations, and, if possible, interactive platforms, placing the user in a more active role in the learning process. Another relevant issue is that the tools should be easily managed by any user, even if they display only basic computer skills (11, 41).

After the immunology website identifications, an analysis concerning each resource was performed, based on several criteria used for educational resource evaluations (11, 41), displayed in Table 1.

It should be emphasized that all analyses were based only on the immunology content of each educational resource and were carried out by two authors with adequate knowledge of immunology and cellular biology (at least 5 yr of immunology or cellular biology teaching). The assessments were carried out in a blind manner, i.e., one author did not have access to the evaluation results of the other professional, to avoid subjective analyses. In cases of divergent results, a third professional (someone with >10 yr of experience in both immunology teaching and development of educational resources) was recruited to analyze the educational resource, according to the established criteria (Table 1).

Finally, as web access through smart phones and tablets is progressively increasing, the last tool updates and the compatibility with mobile devices (21) for each selected educational resource were identified whenever possible.

RESULTS

The search for educational immunology teaching and training animations returned a high number of hits (over 40,000) concerning short animations in international websites, including video classes, cartoons, and animations. However, the particular search for OER aimed at immunology learning developed by educational or research institutions or professionals returned a low number of freely available internet resources, as related to the amount of total information in the field. Nonetheless, several educational resources on the internet were found, presented as quite attractive and user-friendly tools, with colorful three-dimensional graphics and motivational environments. Furthermore, content-clear and interactive animations can be found on a number of websites (Table 2). Some of the listed sites, displaying distinct features as educational resources in immunology, are discussed below.

The Howard Hughes Medical Institute has a website dedicated to educational material, named BioInteractive (17). This site supports the production of several educational materials directed toward students, comprising several expected features for a successful web educational tool, including a well-defined scope, author descriptions, teacher guidance, worksheets to test the learned content, and different interactive resources, such as animations and movies. Four specific topics referring to im-

Table 1. Criteria used in the evaluation of educational resources

| Criteria                | Definition                                                                 |
|-------------------------|---------------------------------------------------------------------------|
| Content clarity         | Immunology content information should be clear and consistent, facilitating comprehension. It must be appropriate for the target audience (undergraduate students). |
| Motivational resources  | Refers to the ability of the educational resource to attract user attention, e.g., multimedia resources, playful elements. |
| Easy to use             | Refers to navigation ease without the user having to resort to manuals, even if he/she does not present in-depth knowledge of computer resources. |
| Interactivity           | A resource that involves a more active user participation, which can interfere with or define its use. |
| Learning evaluation     | Presents resources for learning verification, through exercises or problem situations. |
| Site/Contents                                                                 | Country      | Content Clarity | Motivational Resources | User-friendly | Interactivity | Learning Evaluation | Support | Mobile Compatibility | Last Update | Electronic Address                                                                 |
|------------------------------------------------------------------------------|--------------|-----------------|------------------------|---------------|---------------|--------------------|---------|---------------------|-------------|-----------------------------------------------------------------------------------|
| Anatomy & Physiology—Student Edition, website by Online Learning Center      | United States| Yes             | Yes                    | Yes           | Yes           | Yes                | Adobe Flash, Adobe Shockwave, and Java | No       | 2018                 | http://highered.mheducation.com/sites/0072507470/student_view0/chapter22/animation_theimmune_response.html |
| The Crash Course anatomy and physiology website contains video lessons with  | United States| Yes             | Yes                    | Yes           | No            | No                 | YouTube*          | Yes      | 2018                 | https://www.thecrashcourse.com                                                                 |
| quizzes and animations on anatomy, physiology, and immunology, referring to | The CELLS alive! website contains games, images, quizzes, and videos on   | United Kingdom       | Yes                    | Yes           | No            | Yes                | HTML               | Yes      | 2 018                | https://www.cellsalive.com/                                                                 |
| the book (29).                                                              | various areas, such as immunology, cell biology, microbiology and genetics. It was developed by scientist and graphic artist James A. Sullivan (42). | Yes                    | Yes                    | Yes           | No            | Yes                | No                  | Yes      | 2018                 | http://www.roitt.com/default.asp                                                                 |
| The Immunology website contains texts, animations, and images on basic immunology and immunological techniques (44). | NI           | Yes             | Yes                    | Yes           | No            | No                 | HTML               | Yes      | 2018                 | http://theimmunology.com/                                                                 |
| The Nature Immunology website contains articles, videos, and animations (28). | United States| Yes             | Yes                    | Yes           | No            | No                 | No                 | Yes      | 2018                 | https://www.nature.com/ni/multimedia/index.html                                                                 |
| The Khan Academy educational videos are on immunological topics (available in other languages) (22). | United States| Yes             | No                     | Yes           | No            | No                 | YouTube*          | Yes      | 2018                 | https://www.khanacademy.org/science/biology/human-biology/#immunology                                                                 |
| The BioInteractive website was developed by the Howard Hughes Medical Institute and presents a simulator in which students can practice techniques used in immunology laboratories (17). | United States| Yes             | Yes                    | Yes           | Yes           | No                 | No                 | Yes      | 2018                 | https://www.hhmi.org/bio/interactive/                                                                 |
| Roi tt’s Essential Immunology website, Resources, contains animations, videos, figures, and exercises from the Essential Immunology book (34). | United States| Yes             | Yes                    | Yes           | No            | Yes                | No                 | Yes      | 2018                 | http://www.roitt.com/default.asp                                                                 |
| The CENGAGE Learning website, Assignment Library, contains videos, animations, and quizzes (6). | United States| Yes             | Yes                    | Yes           | No            | Yes                | Adobe Flash        | No       | 2018                 | https://www.cengage.com/biology/discipline_content/apla_pages/solomon9e/ch45.html                                                                 |
| Immunology Videos website was developed by the University of Toronto (20).   | Canada       | Yes             | Yes                    | Yes           | No            | No                 | No                 | Yes      | 2018                 | http://www.immunology.utoronto.ca/immunology-videos                                                                 |
| Virtual immunology software was developed by the Laboratory of Cellular Communication from Oswaldo Cruz Foundation and contains interactive animations about immunology, physiology, and medical education (available in Portuguese and English) (5). | Brazil        | Yes             | Yes                    | Yes           | Yes           | No                 | No                 | Yes      | 2018                 | http://www.kc.fioeh.com                                                                 |
| The BigPicture website contains animations, videos, articles, and activities about the immune system (3). | United Kingdom| Yes             | Yes                    | Yes           | No            | No                 | YouTube*          | Yes      | 2016                 | https://bigpictureeducation.com/                                                                 |
| The Merlot collection contains American university lectures and summaries on immunology (25). | United States| Yes             | No                     | No            | No            | No                 | Adobe Flash, PowerPoint, and Windows Media Video | Not all resources | 2014 | https://www.merlot.org/merlot/materials.htm?keyword=
| The Immunobiology interactive website contains thematic animations on immunology to accompany Janeway’s Immunobiology textbook (4). | United Kingdom| Yes             | Yes                    | Yes           | No            | No                 | Adobe Flash        | No       | 2007                 | http://www.blink.hirz/immunoanimations/index1.html                                                                 

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munology are found at this site: a guide to teach immunology, as part of the institutional interactive media resources; a click-and-learn resource about immune system cells [which is accessed from an acquired immune deficiency syndrome (AIDS) topic], accompanied by a student worksheet; and two animation resources concerning effector T lymphocytes, where one describes the events involving antigen recognition by T-helper cells and consequent clonal proliferation, and the other concerns the viral extermination activity of cytotoxic T cells. This website comprises an interactive resource that simulates an immunology laboratory by employing animation and hypermedia data, allowing the user to experience a typical laboratory test and learn from associated concepts (direct virtual laboratory access: https://www.hhmi.org/biointeractive/explore-virtual-labs).

Anatomy & Physiology—Student Edition is another site that fits all of the criteria applied to evaluate a resource as educational (although it does not support mobile devices) (29). This site contains online content from the book Anatomy and Physiology, 6th edition, by authors Rod Seeley, Trent Stevens, and Philip Tate, all from Idaho University and Fenix College (37). The website also contains animations and interactive activities concerning anatomy and physiology. In chapter 22, “Lymphatic System and Immunity,” students can watch animations on immune cells, antibodies, and immune responses. Furthermore, they can answer questions concerning immunity in a quiz format or study offline and take part in interactive activities, such as labeling exercises, crossword puzzles, flashcards, and concentration game.

CELLS alive! is also an interesting website, offering several animations concerning different scientific areas, including immunology, and also presenting puzzles and quizzes for learning evaluations (42). The animations are very didactic and compatible with mobile devices.

The virtual Immunology site is also noteworthy (2). Developed by the Laboratory of Cellular Communication, at the Oswaldo Cruz Foundation, this website presents interactive animations that allow the user to manipulate events using a computer handheld pointing device (mouse). All steps are followed by explanatory audio and subtitles, and the animations present a real situation in which students can observe immunological events and interact during different stages. Currently, it is not compatible with mobile devices, but the team is working on developing this compatibility.

Although its contents are interesting and didactic, three sites presented in Table 2 have not been updated in the last 10 yr. Immunobiology Interactive (4) presents thematic animations on immunology to accompany the textbook Janeway’s Immunobiology (27). The animations are didactic concerning several important immunology topics, part of the 7th edition of the book, last updated in 2007, and incompatible with mobile devices.

The same is noted for the website Interactive animations, obtained from Benjamin Cummings’ Microbiology Animations (31). The website contains animations on several physiology, cellular and molecular biology and immunology themes. These online animations are part of a CD-ROM belonging to microbiology textbooks from publisher Benjamin Cummings. This website is also incompatible with mobile devices, and its last update was in 2005.

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Table 2. —Continued

| Site/Contents | Country | Content Clarity | Conten...
The Biology Project website, developed by the University of Arizona (9), although meeting all of the criteria used for the evaluation of educational resources, especially interactivity, which is equivalent in most of the listed sites, is outdated (last updated in 2002). The site contents are presented in a clear and didactic way through problem sets and tutorials, and it also presents interactive activities concerning immunological techniques, such as ELISA and Western blotting, applied to an HIV/AIDS test.

The MERLOT collection was developed by California State University System in partnership with education institutions, professional societies, and the industry (25). This collection houses a series of contents related to immunology (lectures, activities, summaries, PowerPoint presentations) by several American universities. Thus, when the student clicks on the selected content, he/she is redirected to the source site of the content. However, many source sites are already offline.

Some sites featuring immunology content through educational videos have their access redirected to YouTube, such as BigPicture (3), Immunology Videos (20) (developed by the University of Toronto), Khan Academy (22), and Nature Immunology (28) websites. All are compatible with mobile devices. The Crash Course website (7), also hosted on YouTube, is likewise noteworthy. Crash Course is an educational YouTube channel currently featuring over 1,000 videos, hosted by Hank Green and created by the Crash Course team, with 600 million views. It provides educational videos in a clear and attractive way with didactic animations concerning various areas of knowledge that can be freely accessed by a mobile device. Minicourses are offered for various age groups and education levels. The site is formed by a multidisciplinary team, counts on expert advice, and is an interesting tool for students, teachers, and the nonspecialized public.

A shortage of free immunology games available on the internet was noted, especially compared with the number of games concerning other areas, such as cell biology. In this scenario, three websites containing immunology games are noteworthy. The first is Science Game Center (26), which offers games compatible with the iOS platform in various science areas, including immunology. Each game also presents information/discussions of certain concepts by experts. The Sporcle website (39) features quizzes concerning specific immunology content, where the user can evaluate his/her knowledge in an interactive way. Finally, the site PurposeGames (33) presents games on the lymphatic and complement system and other immunology themes. All are compatible with mobile devices.

Other games containing modern hypermedia features, such as Immune System Defender (available on the Nobel Prize website), ImmuneQuest (a project funded by the National Science Foundation), Immune Defense (available at http://www.molecularjig.com/), and “Immune Attack” (funded by the National Science Foundation) are both commercially available and available in a demo version.

DISCUSSION

The use of technology in the teaching-learning process is entirely justified when considering that one of the basic education aims is to prepare students to be citizens of a pluralistic, democratic, and technologically advanced society (23). In this context, informatics has been a critical enabling tool, ensuring content suitability from linguistic, political, and social aspects.

Currently, technology and education are seen as an inseparable relationship, as technology applications are directly in line with the new proposals for high standard education. The traditional teaching process, lacking a dynamic structure, as observed in the case of immunology teaching, does not always offer a real experience and the theory-practice connections made possible by the computational resources (19). However, even with a significant potential as a teaching and learning process facilitator, access to adequate educational software is limited.

Ultimately, since content precision is a critical characteristic for using site information as an active teaching/learning tool, it is important to note that the data curation at the websites cited in this study is another critical regulatory issue. To certify accurate and high-quality information for internet users, immunologists should engage in such a specialized education activity. In this context, immunology societies could help in fostering specialized groups aiming to analyze and provide current criticism regarding freely available internet information, as well as produce educational material from conception to completion or create a quality certificate for adequate sites based on transparent criteria. Thus specialists and educators could provide the means to improve ex nihilo website constructions or even to direct precise content corrections by direct advice to OER producers.

The main idea of this study is to map and assess educational animations in immunology, using empiric criteria (Table 1) developed by our group based on the current literature (11, 41). Several sites are clearly outdated. Many animations are developed in Flash, which was discontinued in 2016 (16). Nevertheless, a new software named Animator CCR was launched by Adobe, a Flash successor, that can function on several desktop operational systems (Windows and macOS), as well as Android and iOS mobile devices (https://www.adobe.com/creativecloud/catalog/mobile.html). In addition, some animations also use the same file as Flash, the FLA (XFL, Adobe file, which is based on XML files, but is not, to the best of our knowledge, an open source software) (32). It should be pointed out that not all animations are developed with open software, i.e., despite being freely available online, they cannot be considered by definition open animations, since they are not produced using an open software.

Additionally, periodic revision is warranted to cope with evolving technologies and progressive knowledge production. Similarly, it is also important to validate the instruments employed to analyze website contents. In fact, concerns stated by guidelines and studies that approach instrument and suitability criteria applied to quality assessments of internet-based information, particularly regarding healthcare issues, are not new (14, 45).

Concluding remarks. The use of computer and mobile devices, through animations, videos, games, and educational software, has been progressively included as an effective auxiliary tool in the teaching process. However, even displaying significant potential as teaching and learning process facilitators, access to adequate educational software is still limited. Moreover, educational software will not reach its goal if no assessment of the procedures applied by a multidisciplinary team, since its conception, are carried out. Thus OER producers

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should assign a board to assess all software creation steps, including technical staff and end users, i.e., teachers and students. Particularly in the case of immunology, it is understood that implementing a system that attempts to realistically approach a biological phenomenon, even if carried out in a simplistic way, is extremely difficult. Thus, making the use of educational software a permanent trend might be a fruitful strategy in the teaching-learning process, directing the learning process toward a more motivating, interactive, and dynamic activity for students.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

T.F. and L.A.A. conceived and designed research; T.F. and N.C.d.S.F. performed experiments; T.F., N.C.d.S.F., V.C.-d.A., and L.A.A. analyzed data; T.F., N.C.d.S.F., V.C.-d.A., and L.A.A. interpreted results of experiments; T.F. and L.A.A. edited and revised manuscript; T.F., R.M.L., A.A.F.-N., and L.A.A. approved final version of manuscript; N.C.d.S.F., R.M.L., A.A.F.-N., and V.C.-d.A. drafted manuscript.

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