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EDUCATION

# Analysis of undergraduate cell biology contents in Brazilian public universities

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## Abstract

The enormous amount of information available in cell biology has created a challenge in selecting the core concepts we should be teaching our undergraduates. One way to define a set of essential core ideas in cell biology is to analyze what a specific cell biology community is teaching their students. Our main objective was to analyze the cell biology content currently being taught in Brazilian universities. We collected the syllabi of cell biology courses from public universities in Brazil and analyzed the frequency of cell biology topics in each course. We also compared the Brazilian data with the contents of a major cell biology textbook. Our analysis showed that while some cell biology topics such as plasma membrane and cytoskeleton was present in ∼100% of the Brazilian curricula analyzed others such as cell signaling and cell differentiation were present in only ∼35%. The average cell biology content taught in the Brazilian universities is quite different from what is presented in the textbook. We discuss several possible explanations for these observations. We also suggest a list with essential cell biology topics for any biological or biomedical undergraduate course. The comparative discussion of cell biology topics presented here could be valuable in other educational contexts.

**Keywords:** Brazilian universities; cell biology; syllabus; undergraduate students

## Introduction

Teaching cell biology to undergraduate students involves a huge challenge: which core topics, and at what level of complexity, should we be teaching? Cell biology is an ever-growing area of the biological and biomedical sciences and the amount of knowledge accumulated in the last few years is massive. A difficulty in dealing with such an enormous amount of information is not to fall into content-based rather than concept-based teaching (Allen and Tanner, 2003). As suggested by many authors, one approach would be to focus on a limited set of core ideas (D'Avanzo, 2008; Howitt et al., 2008).

One way to define a limited set of key ideas in cell biology is to analyze what a specific cell biology community is teaching their students. A simple analysis of the syllabi used in cell biology courses can provide the basic information regarding which cell biology topics have been selected in a community, such as colleges and universities. Each syllabus contains a descriptive summary of topics to be covered in each course. A list of the current cell biology topics, obtained from all the syllabi, could be used to generate an inventory of the essential ideas in cell biology. Analysis of this inventory could help to identify educational deficiencies, particularly when compared to well-defined content lists from well-known cell biology textbooks. Furthermore, this community inventory could be compared to concept inventories, which includes standardized tests that aim to examine student understanding of previously identified core concepts or grand ideas (Khodor et al., 2004; Howitt et al., 2008; Shi et al., 2010).

It is important to point out that curricula in Brazilian universities are usually centered around specific professional careers. In Brazil, several universities resulted from the fusion of professional schools such as medicine and engineering, and today most undergraduate courses correspond to careers. Thus, an undergraduate student enters the university through a selection process that is specific for each major, such as

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**Abbreviations:** ASCB, American Society of Cell Biology; SBBC, Brazilian Society for Cell Biology; UERJ, State University of Rio de Janeiro; UFBA, Federal University of Bahia; UFC, Federal University of Ceará; UFMG, Federal University of Minas Gerais; UFPI, Federal University of Piauí; UFRGS, Federal University of Rio Grande do Sul; UFRJ, Federal University of Rio de Janeiro; UFRN, Federal University of Rio Grande do Norte; UFSC, Federal University of Santa Catarina; UNICAMP, State University of Campinas; USP, University of São Paulo; USP-RP, University of São Paulo—Ribeirão Preto

medicine, and then the student attends classes in a sequence of required subjects, usually including cell biology. So, typically, medical students do not attend classes with other students, and each course has a separate, dedicated sequence of classes each semester with a specific syllabus. Therefore, the same university has several syllabi for the same topic (e.g., cell biology) that are specific for different majors (e.g., medicine, or pharmacy). This structure allowed us to perform the present analysis. The independent origin and administration of each course led to quite different cell biology content organization and complexity.

Considering the Brazilian context of diverse career-oriented courses, it is not the intention of the present study to broadly discuss curriculum mapping and design (Anderson and Rogan, 2011). It is common in Brazil that the curriculum of each career is designed separately, based on initiatives of each professional course from independent schools (e.g., School of Medicine, Department of Odontology), sometimes with little input from faculty of basic science courses. We anticipate that the proposal for a minimal cell biology content presented here could contribute toward curriculum reform.

The main goal of our study was to collect and analyze the current cell biology syllabi that are in use in Brazilian public universities. We analyzed the number of cell biology topics in each course, the name of each topic, and the percentage of each course devoted to that topic. Our analysis also included the duration of each course, which is an indicator of the presumed importance of cell biology within the student curriculum as a whole. We also compared the Brazilian data with the contents of a major cell biology textbook. Finally, we propose a list of cell biology topics that might be considered essential for all undergraduate cell biology classes.

We are aware that the syllabi do not fully describe the contents of each course, which is a limitation of our study. On the other hand, the way course material is organized into topics is itself an indication of cell biology priorities.

We are not aware of any similar description or discussion of cell biology core contents, probably because of the specific organization of undergraduate courses in Brazil. Although this course organization in Brazil is different from that in other countries, the comparative discussion of cell biology topics presented in this study could be extended to places that do not have such a career-oriented organization. This survey provides the first picture of cell biology teaching in Brazilian universities. We also discuss how the history of the cell biology field in Brazil influenced the current syllabi.

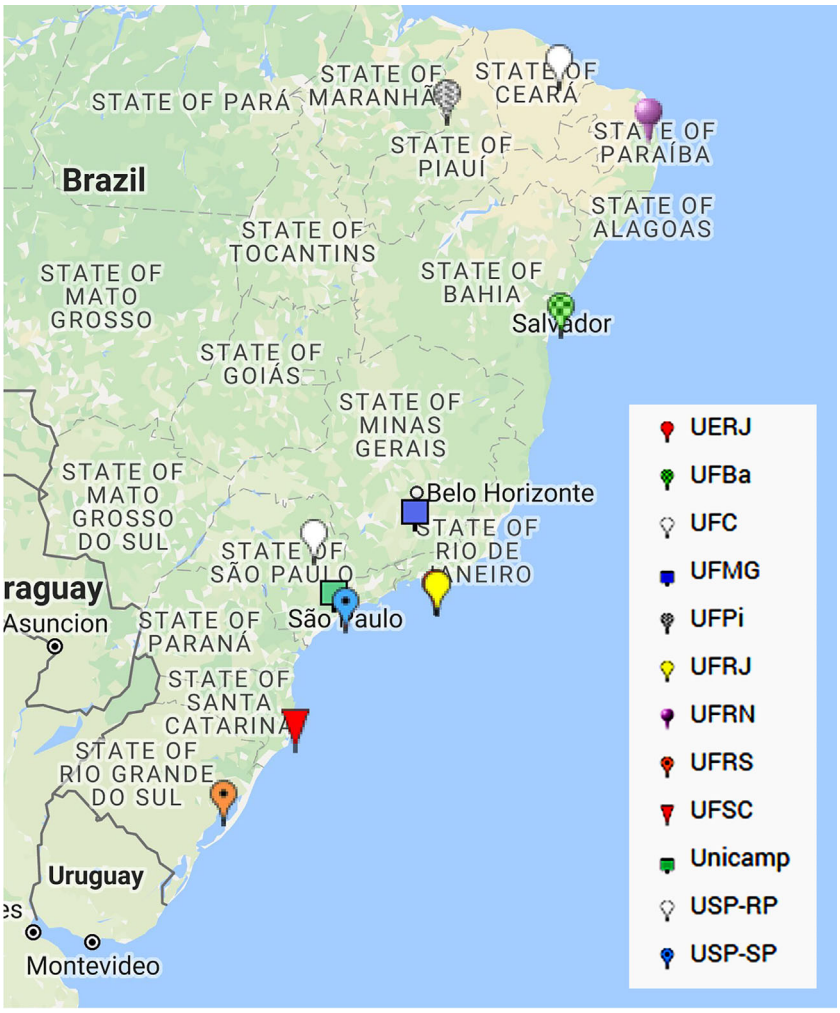
## Materials and methods

First we collected cell biology syllabi from 12 Brazilian public universities: Federal University of Bahia (UFBA), Federal University of Ceará (UFC), Federal University of Minas Gerais (UFMG), Federal University of Piauí (UFPI), Federal University of Rio de Janeiro (UFRJ), Federal University of Rio Grande do Norte (UFRN), Federal University of Rio Grande do Sul (UFRGS), Federal University of Santa Catarina (UFSC), State University of Campinas (UNICAMP), State University of Rio de Janeiro (UERJ), University of São Paulo (USP), University of São Paulo-Ribeirão Preto (USP-RP). These universities serve the major populated regions of Brazil: south, southeast and northeast. Each one offers different majors in which there are independent cell biology courses. Seventeen careers that offer cell biology course material were included: Aquaculture, Biology, Biomedicine, Dentistry, Phonoaudiology, Food Technology, Medicine, Nursery, Nutrition, Oceanography, Occupational Therapy, Pharmacy, Physical Education, Physiotherapy, Psychology, Social Health, and Zootechnology. All these data were collected either directly from the website of each university, or when not available online, from university cell biology teachers, by email. One example of a syllabus from a specific cell biology course is shown in Supplementary Material. This example illustrates the format of all the syllabi we received (either by download from the website or from professors). From this example, it is possible to see the information related to the list of cell biology topics given in a specific course. Then, we organized on a spreadsheet all the data related to the different cell biology topics offered for each course. Finally, we quantified the number of topics in each course and the percentage of material devoted to each topic. The results were plotted using Microsoft Excel. The map showing the Brazilian regions was created using the website mapalist.com.

We also compared these Brazilian data with the contents of the cell biology textbook "Molecular Biology of the Cell," by Alberts et al. (2002). We used the 4th edition of this book, which is the most recent one that is freely available on the PubMed website. We counted the number of pages in this book that are dedicated to each cell biology topic and calculated their percentages in relation to the book as a whole. Values were represented as the mean $\pm$ standard deviation.

## Results and discussion

The main goal of the present study was to assemble and analyze the cell biology contents that are in use at public universities in Brazil. First, we collected data from cell biology syllabi of 17 undergraduate courses from 12 Brazilian public universities (for details, see Materials and Methods section and Figure 1). As mentioned, Brazilian universities usually have a tightly defined curriculum for each major leading to a specific career. A total of 50 different courses, all of which have cell biology content, were analyzed. Analysis of the course titles (e.g., Cell Biology and Embryology) serves to illustrate the broad interface that




UERJ - State University of Rio de Janeiro
UFBa - Federal University of Bahia
UFC - Federal University of Ceará
UFMG - Federal University of Minas Gerais
UFPi - Federal University of Piauí
UFRJ - Federal University of Rio de Janeiro
UFRN - Federal University of Rio Grande do Norte
UFRS - Federal University of Rio Grande do Sul
UFSC - Federal University of Santa Catarina
Unicamp - State University of Campinas
USP-RP - University of São Paulo / Ribeirão Preto
USP-SP - University of São Paulo

**Figure 1** List of the public Brazilian universities that participated in this study and the Brazilian map showing their locations.

cell biology shares with other biomedical sciences, such as biochemistry, biophysics, developmental biology, embryology, genetics, histology and molecular biology (Table 1). As discussed by Tibell and Rundgren (2010), the content of molecular life science is inherently complex and deeply rooted in diverse related subjects. Interestingly, we found courses entitled simply Cell Biology in only a few cases. This could be a consequence of the history of the cell biology area in science in the world and specifically in Brazil, as cell biology is a relatively new field compared to histology, for

**Table 1** List of the Brazilian undergraduate courses containing cell biology topics and included in this study.

| |
|---|
| Basic morphology |
| Biological basis of physiotherapy |
| Biology |
| Cell biology |
| Cell biology and embryology |
| Cell biology and genetics |
| Cell biology, histology and embryology |
| Cellular and molecular biology |
| Cytology and histology |
| Histology |
| Histology and embryology |
| Introduction to the study of medicine |
| Molecular biology |
| Molecular biology of the cell |
| Structural basis of living cells |
| The cell |

instance. This novelty is probably why we found courses in which cell biology is still considered only as an introduction to histology or embryology, and the course titles (e.g., Histology) as well as the extent of cell biology topics reflect the relatively smaller importance devoted to the cell biology content in these cases. On the other hand, it is important to recognize that cell biology provides basic concepts that are necessary for the full comprehension of other areas, such as embryology, developmental biology, and histology. Therefore, it is reasonable that cell biology should be in many cases presented as an introduction to other related courses.

Another interesting point is that some of the Brazilian courses still have the title Cytology instead of Cell Biology (Table 1). In the last 50 years, the term Cytology has been replaced by Cell Biology in all the cell biology textbooks, scientific journal titles, courses, and department names around the world. While Cytology is commonly associated with a more descriptive approach, Cell Biology tends to have a more mechanistic and integrated view of cellular structures and processes.

Not all undergraduate programs offer cell biology as an independent course, or even as a separate topic within another course. In fact, we encountered some courses that do not present key topics in cell biology in any way. In a preliminary survey of medical schools from 12 Brazilian public universities, we found that 84% had cell biology contents in their curricula. The fact that not all of them teach cell biology is surprising since cell biology includes basic concepts that are essential for the understanding of normal and pathological human conditions. By understanding how cells work in healthy and diseased human states, one can hope to develop new strategies toward the prevention and treatment of diseases, including the development of new vaccines, more effective medicines, innovative cell and gene therapies, and new diagnostic tests, among many other applications relevant to human health (Weatherall, 1998). The remarkable possibilities that the rapidly growing cell biology field can offer in the future have particular implications for medical education.

We also analyzed the duration (in hours) of the cell biology courses. We found a wide range: from 15 to 170 h, with an average of 68 h per course per semester. In principle, the shorter the course, the smaller the amount of cell biology material that is going to be covered. However, we assume that there is no necessary correlation between the quality of a course and its duration. Notwithstanding the fact that quality is difficult to define, several factors could have an impact on the quality of a course, including teaching performance, teaching material, teaching method, frequency of class meetings, length of class meetings, length of course, student maturity, and student background, among others. Course length is only one of these factors and thus course quality cannot rely exclusively on this single measurement. For example, it has been shown that, in some cases, students perform better (in terms of retention and terminal performances) in compressed courses (intensive courses given in a few weeks) than they do in full semester courses (Lee and Horsfall, 2010; Sheldon, 2010). The cited authors suggest that cohesion develops in compressed classes and that is accompanied by an intense mental involvement of the students. Students tend to become better acquainted with the course material and to pursue an understanding of course material more avidly.

Next, we listed all the cell biology topics that were present in the 50 courses analyzed (Table 2). Twenty-eight different cell biology topics were identified. We found some unexpected topics, such as Cytoplasm, Viruses, and Bioengineering, although these appeared in a minority of the courses analyzed. We believe that these topics may reflect a descriptive view of Cell Biology (in the case of Cytoplasm), or they may represent an attempt to provide a more applied approach to the subject (in the cases of Viruses and Bioengineering). Table 2 shows the 28 cell biology topics in the sequence in which they appear most frequently in the syllabi analyzed in this study. We believe that this specific list and sequence of topics/contents were decided at the time these courses were first created, and after that they were passed to new teachers without major changes. As discussed by Tanner and Allen (2002), in most universities during the creation of a new course, the process of selecting course content is an extremely local enterprise. Sometimes the decisions are made by a small group of faculty members, but most often they are made by a single professor—the one with the responsibility of teaching the course.

The sequence of topics can be very informative. It is interesting to see that some of the courses begin with an evolutionary approach (Table 2) and then only a few courses move to a basic knowledge of the main molecules ("Biomolecules") that make up living cells (DNA, RNA, lipids, proteins, and sugars). "Methods in Cell Biology" is the next topic covered in most courses. This topic includes

**Table 2** List of all of the cell biology topics present in the Brazilian courses included in this study.

| | |
|---|---|
| 1 | Evolution of cells |
| 2 | Molecules |
| 3 | Methods in cell biology |
| 4 | Plasma membrane |
| 5 | Cytoplasm |
| 6 | Cell adhesion and junctions |
| 7 | Cytoskeleton |
| 8 | Nuclear structure |
| 9 | Endoplasmic reticulum |
| 10 | Golgi apparatus |
| 11 | Lysosome |
| 12 | Endocytosis |
| 13 | Cell signaling |
| 14 | Cell cycle |
| 15 | Cell death |
| 16 | Cell differentiation |
| 17 | Mitochondria |
| 18 | Peroxisome |
| 19 | Extracellular matrix |
| 20 | Regulation of gene expression |
| 21 | Cellular metabolism |
| 22 | Plant cells |
| 23 | Viruses |
| 24 | Prokaryotic cells |
| 25 | Stem cells |
| 26 | Cancer |
| 27 | Bioengineering |
| 28 | Genomics and proteomics |

several cell biology techniques: electrophoresis, Western blotting, chromatography, optical and electron microscopy, fluorescence, conventional and confocal microscopy, cell fractionation and isolation, cell sorting, cell culture, cell transfection, and basic molecular biology. Next, most of the courses include topics related to the outer part of the cell, the plasma membrane, and then cover all the major organelles (nucleus, endoplasmic reticulum, Golgi, lysosome, mitochondria, peroxisome, and vesicles) and the cytoskeleton. Topics related to cellular processes (cell cycle, cell death, cell signaling, and cell differentiation), when present, are usually covered after the main organelles. This could be an attempt to correlate structure and function of each organelle in relation to the processes involved.

Then, we analyzed the frequency of each of the 28 topics in the 50 courses (Figure 2). Interestingly, some cell biology contents such as plasma membrane and cytoskeleton were present in 95–100% of the courses analyzed, and others such as cell signaling and cell differentiation were found in only 30–40% of them (Figure 2). These results suggest a content-based approach rather than concept-based teaching, since both cell signaling and cell differentiation are concept-based topics that depend on a more integrated view of the cell. It is possible that the topics cell signaling and cell differentiation are in some cases included in other courses such as biochemistry and biophysics. The question remains open as to whether these two topics should be included within the core cell biology course and context.

To have an external reference, we compared our data with the contents of one of the most popular cell biology

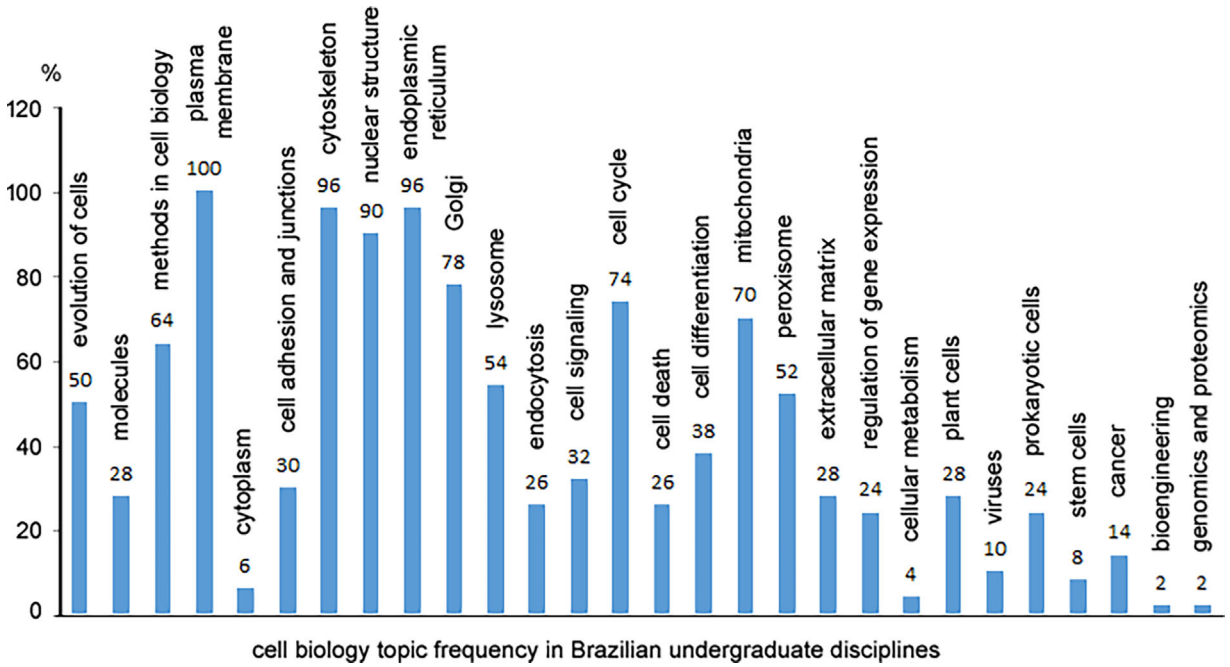



**Figure 2** Percentage of time devoted to each cell biology topic present in the Brazilian courses included in this study.

textbooks: "Molecular Biology of the Cell," by Alberts et al. (2002) (4th edition). Alberts et al. (2002) summarize cell biology in the following twenty-one major topics: (1) cells and genomes, (2) cell chemistry and biosynthesis, (3) proteins, (4) DNA and chromosomes, (5) DNA replication, repair, and recombination, (6) how cells read the genome: from DNA to protein, (7) control of gene expression, (8) manipulating proteins, DNA, and RNA, (9) visualizing cells, (10) membrane structure, (11) membrane transport of small molecules and the electrical properties of membranes, (12) intracellular compartments and protein sorting, (13) intracellular vesicular traffic, (14) energy conversion: mitochondria and chloroplasts, (15) cell communication, (16) the cytoskeleton, (17) the cell cycle and programmed cell death, (18) the mechanics of cell division, (19) cell junctions, cell adhesion, and the extracellular matrix, (20) development of multicellular organisms, and (21) cancer.

This organization of the topics in the Alberts textbook shows differences from the data we collected from the Brazilian universities (Table 2). Interestingly, only 19 topics (out of 28) from the Brazilian universities (Table 2) were found in this textbook (Figure 3). Some of the Brazilian

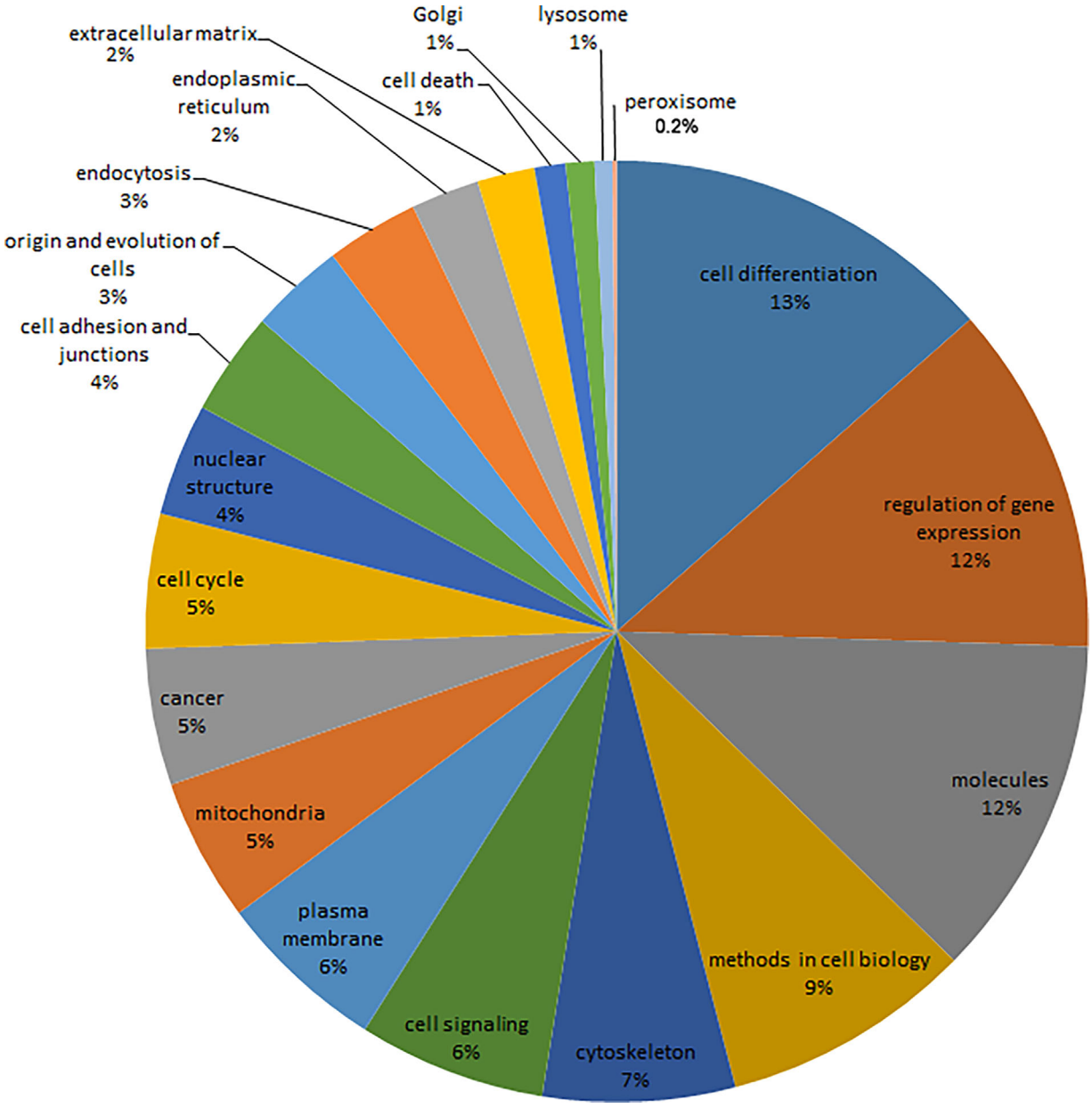



**Figure 3** Cell biology topics present in the textbook "Molecular Cell Biology," by Alberts et al. (2002)

topics are joined together in the book, such as cell cycle and programmed cell death, and others are present in more than one topic in the book, such as manipulating proteins, DNA, and RNA; and visualizing cells (both classified as Methods in Cell Biology in the Brazilian data). The following Brazilian cell biology topics are not present in the summary of this book: Bioengineering, Cytoplasm, Metabolism, Plant Cells, Prokaryotic Cells, Stem Cells, and Viruses. The absence of these topics from the summary of the book does not mean that these topics are absent from the book, but they are not defined as a major topic that deserves being in the summary.

To evaluate the relative importance of each cell biology topic in the book, we compared the number of pages in the book that are dedicated to each topic (Figure 3). Cell Differentiation (13%), Regulation of Gene Expression (12%), and Molecules (12%) are among the three contents present in higher percentages in this textbook, followed by Methods in Cell Biology (9%), Cytoskeleton (7%), Cell Signaling (6%), and Plasma Membrane (6%). The cell biology contents that are less represented (~1%) in this textbook are Cell Death, Golgi apparatus, Lysosomes, and Peroxisomes. From this analysis, it is possible to conclude that areas considered relatively important by Alberts et al. (2002) are not well represented in the Brazilian courses (e.g., Cell Differentiation and Regulation of Gene Expression).

Here we propose a list of the minimum cell biology content to be covered in any cell biology undergraduate course (Table 3). This proposal is intended for any biological or biomedical undergraduate course, despite the heterogeneity of different careers that is typical of Brazilian universities. We organized this list with a sequence of fourteen topics based on: (i) the Cell Biology Learning Framework prepared by members of the American Society of Cell Biology (ASCB), which contains learning goals and objectives that the ASCB agrees any undergraduate biological sciences major should know about cell biology by the time he or she graduates (http://www.coursesource.org/courses/cell-biology); (ii) the content of the four textbooks "Molecular Biology of the Cell" by Alberts et al. (2014), "Molecular Cell Biology" by Lodish et al. (2000), "The Cell: A Molecular Approach" by Cooper and Hausmann (2013), and "A Célula" ("The Cell") by Carvalho and Recco-Pimentel (2013); (iii) discussions within the Undergraduate Program for Cell and Developmental Biology of the Biomedical Sciences Institute of UFRJ; (iv) discussions within the Brazilian Society for Cell Biology (SBBC); and (v) both authors' long experience in teaching cell biology at the Federal University of Rio de Janeiro (UFRJ). This tentative list attempts to integrate the study of the formation, structure, components, and function of cells. Obviously, this list of contents should be adjusted to the total number of hours that each cell biology course has available, either by increasing the depth of each topic, or by adding new topics. It is important to point out that these contents can be delivered in very different formats, such as lectures, hands-on laboratory practical classes, seminars and discussions about scientific papers. It has been shown that discussions where students are required to solve a scientific research problem can greatly improve their learning capabilities in the biological and biomedical field (Wright and Klymkowsky, 2005; Wood, 2009). Comparing our suggested list of cell biology contents (Table 3) with the summary of the Alberts book (Figure 3) it is apparent that some topics that are expanded in the book are joined together in our list, such as Methods in Cell Biology, and other topics present in the book are omitted from our list, such as Development of Multicellular Organisms and Cancer. These decisions were made to create a list with the essential cell biology topics, leaving other topics to be covered in other related and/or more advanced courses. On the other hand, we included topics such as gene regulation, even though they are commonly discussed in other courses, to strengthen the integration between topics, and reinforce the overall logic of the cell.

**Table 3** List of the minimum and essential cell biology content for biological and biomedical undergraduate courses.

| | |
|---|---|
| 1 | Evolution in cell biology |
| 2 | Methods in cell biology |
| 3 | Membranes* |
| 4 | Cytoskeleton and cell motility |
| 5 | Cell adhesion and junctions |
| 6 | DNA replication* |
| 7 | RNA synthesis and regulation of gene expression |
| 8 | Nuclear structure |
| 9 | Protein synthesis and degradation |
| 10 | Endoplasmic reticulum and Golgi apparatus |
| 11 | Mitochondria and energy conversion* |
| 12 | Cell cycle and cell death |
| 13 | Cell signaling and communication |
| 14 | Cell differentiation |

*These topics are within the boundary of other related courses, such as biochemistry, biophysics and genetics, and can be further addressed in any of them.

In 2009 the American Association for the Advancement of Science (AAAS) prepared a report (visionandchange.org) where it is stated that to be scientifically literate, undergraduate life-science students need to understand the following overarching core concepts: evolution; pathways and transformations of energy and matter; information flow, exchange, and storage; structure and function; and systems-level approaches to biological discovery and analysis. The results obtained from our survey of Brazilian universities (Figure 2) show that students are not exposed to all of these core cell biology concepts. In contrast, our proposed list for the minimum cell biology content (Table 3) contains all the core

cell biology concepts present in the AAAS report (2009). The topic "systems-level approaches to biological discovery and analysis" is expected to be present in all topics, particularly in "methods," "cell signaling," "cell differentiation," and "regulation of gene expression." Examples of systems concepts that should be discussed are: genomics, transcriptomics, proteomics, metabolomics, regulatory networks, homeostasis, feedback loops, and emerging properties.

## Conclusions

Here we have collected and analyzed for the first time the cell biology content that is currently being used for teaching Brazilian undergraduate students in public universities. By comparing these data with a major cell biology textbook and with our previous experiences in cell biology teaching and research, we suggest an essential list of cell biology topics for any undergraduate biological and biomedical course. These data might be used in the development of new strategies aimed at achieving a better comprehension of cell biology in a variety of contexts.

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## Disclosure of potential conflicts of interest

The authors declare that they have no conflicts of interest.

## Author contributions

CM and MLC conceived the study, participated in its design, in the acquisition and interpretation of data, coordination of the study, and in the writing and discussion of the manuscript. Both authors read and approved the final version of the manuscript.

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## Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web-site.

**Figure S1**. Example of a syllabus from a cell biology course offered to undergraduates at a Brazilian public university. This example reflects the format of all the material we received and analyzed.