INTRODUCTION

Knowledge of human physiology is fundamentally important for health professionals, since it provides essential information about the functioning of the human body and its physiological conditions. However, in organizing the curricula of most health courses, this discipline is separated from the social and applied sciences, with the contents studied in the classroom typically being presented to the student in an abstract way. As a result, the student is unable to envisage the human being as a whole, considering all of its biopsychosocial aspects, and does not see the importance of the discipline of physiology for his/her future professional practice (1). Consequently, the teaching-learning of human physiology currently faces great challenges. In addition, considering the increasingly dynamic profiles of the students, there is an ever greater need to adopt methodologies that attract their attention and enable teaching to be both integrative and effective. To this end, teaching-learning methods that involve research can be useful tools to increase interest and encourage the search for knowledge.

Research is a vital component of undergraduate education and can play a key role in students’ learning, their higher education experience, and the development of general skills. Students can be engaged in research and inquiry within their main discipline and across different disciplines (9). An essential condition for research teaching is that the procedures adopted should be both scientific and educational (8). In this approach, the students acquire knowledge of the discipline by undertaking their own research (7). The teacher than passes from being an information transfer agent to being a mediator, challenger, and supervisor, developing knowledge by adopting the attitude of being a permanent researcher, together with the students. This teaching-learning method involves eight steps: observation, question, hypothesis, aims, method, results (data and analysis), discussion, and conclusion (10).

The literature shows that the process of teaching through research motivates the student to develop an investigative attitude and can create opportunities for acquisition of knowledge in a conceptually consistent way, in addition to the development of important skills (6). However, there have been no reported studies concerning the possible use of this methodology, with focus on the teaching of body homeostasis, using simple and easily accessible resources. The goals of the present work, in a critical reflection and considering the current literature, were to integrate research into the traditional teaching of physiology and to evaluate if it would be possible, in terms of practicality and time spent, to apply this didactic methodology to the discipline of human physiology, according to the perception of a university lecturer.

METHODOLOGY

In the second semester of 2017 and the first semester of 2018, the research-based method of teaching-learning was implemented during the courses in human physiology provided to 36 second-year and third-year students of the Biological Sciences Department at the State University of Feira de Santana. This university is a public higher education institution in the city of Feira de Santana, the second most populous city of the State of Bahia, in the northeast region of Brazil. All of the students had previously passed the Human Anatomy, Biochemistry, and Biophysics exams taken during the first academic year. The majority of the students had not previously undertaken research projects, because scientific research methodology is taught after the basic courses (in the third and/or fourth academic years).

The course was offered as a weekly 4-h class during the 15 wk of each academic semester (60 h). One of the guiding principles of the discipline was the development of group research with the theme, homeostasis, during a total of six classes (~24 h). To enhance student engagement, a problem-based collaborative approach to teaching and learning was adopted. To this end, the students of the class were first divided into groups, each with four members, to undertake the eight research steps. The research-based teaching methodology was then developed during 6 consecutive wk (24 h in total). Other classes interspersed throughout the course taught topics that included the physiology of the cardiovascular, respiratory, endocrine, renal, and skeletal muscle systems. In this way, the students had the opportunity to integrate the contents learned in the classroom with the results obtained during the development of their research.

In the 1st wk, to introduce the question to be addressed, the lessons were started with a 5- to 8-min review of previously studied concepts of anatomy, biochemistry, and biophysics, with the introduction of the concept of homeostasis, to stimulate the curiosity of the students. Special attention was given to homeostatic mechanisms that use negative feedback to maintain a constant value (called the set point), as well as those involving positive feedback. In the 2nd wk, a hypothesis was developed. In this step, using a review of the literature, the students raised a hypothesis and then proposed the aims and decided which method(s) to use. In the 3rd and 4th wk, in the laboratory and under the supervision of the teacher, the students recorded, reported, and analyzed the data. The 5th wk involved discussion of the data and the drawing of conclusions, considering the data in relation to the research question(s) posed, and establishing the
conclusions that could be drawn based on the results. The 6th wk was devoted to divulgation of the scientific results, with the groups of students presenting all of the steps of their research during seminars. The subjects involved in the research projects were the students of the course, who performed the activities voluntarily. Based on literature searches, the students proposed and developed an interactive and creative methodology, involving elaboration of the question, the main hypothesis, the experimental design, data analysis, discussion of the results in the classroom, and dissemination of the results.

The approach adopted encouraged the students to search for information, consider the problem, and autonomously develop the research projects, according to four interrelated stages:

1) Bibliographic Review: The development of all of the research projects involved a bibliographic review conducted following the lecturer’s guidance, considering the key questions: how does the human body maintain its homeostasis in response to different environmental situations, what are negative and positive feedbacks, and how can these phenomena be studied in a practical way in the classroom? The review encompassed experimental studies, demonstrations, and the main theoretical references concerning key homeostatic processes, including control of the heart rate (HR), respiratory frequency, blood pressure (BP), and body temperature. This stage included activities including the provision of material (textbooks and other items for practical classes and guided studies), identification of additional resources for study, such as suggestions of websites and blogs, and regular meetings (involving the lecturer and the students) for planning and organizing the methodology to be used, discussing the resources available and how to use them.

2) Human Physiology Classes: The students participated in general human physiology theoretical classes. Among the various topics addressed, special attention was given to the content regarding short- and long-term regulation of BP, cardiac contractility, rhythmic excitation of the heart, respiration, and the autonomic nervous system.

3) Workshops for Data Collection and Analysis (Laboratory Protocols): Under supervision of the lecturer, based on the textbook Practicing Physiology (5) and the work (12), the students carried out measurements of BP by the auscultatory method and HR by counting the beats palpated in the radial artery or in the carotid artery. In addition, visual inspection was used to evaluate the level of distress, use of accessory muscles, respiratory position, chest structure, and respiratory pattern of volunteers in situations of rest and physical stress. During the project workshops and experiments, cardiorespiratory measurements were performed using a sphygmomanometer and stethoscope kit (Welch Allyn Tycos). In addition, for the research topic, “Homeostasis and Temperature,” climatic data of ambient temperature and relative humidity were recorded using the Accu-weather application, available as a free download for Android (https://downloads.accuweather.com/), while a clinical thermometer was used to measure the human body temperature, under the armpit (axillary temperature).

4) Choosing the Projects: According to their interests and in a voluntary way, the groups were instructed to choose the subjects to be studied, as well as the methodology (type of data collection) to be used: case study, experimental research (including environmental and biological measurements), and/or bibliographic review. The idea was to consider the teaching and learning process in an inclusive and much more participatory way, building student knowledge, rather than simply using established material that was already available. As shown in Table 1, the research projects developed had various themes (1.1), with the students selecting diversified experimental protocols (1.2), questions (1.3), hypotheses (1.4), and teaching and learning objectives (1.5). These included exercise practice, the Valsalva maneuver, and dark/light cycle, which focused on cardiovascular, respiratory, and thermoregulatory control, respectively. It is important to note that the students who participated in the experimental protocols had expressed interest in

### Table 1. Research related to the homeostasis themes developed by the students during the theoretical and practical classes of the discipline of human physiology (Biological Sciences Department, State University of Feira de Santana)

| 1.1. Research Theme/Title/Group | 1.2. Data Collection/Experimental Protocols | 1.3. Question | 1.4. Hypothesis | 1.5. Teaching and Learning Objectives |
|--------------------------------|---------------------------------------------|---------------|----------------|--------------------------------------|
| 1.1.1. Homeostasis and Exercise | BP, HR, and RF of volunteers were measured before and immediately after exercise (running for 5 min). | How does the body maintain homeostasis in response to exercise? | During exercise, increases in BP, HR, and RF contribute to maintenance of the partial pressures of oxygen (PO2) and carbon dioxide (PCO2) at normal levels. | Understand cardiovascular and respiratory control in situations of rest and physical exercise. |
| 1.1.2. Homeostatic Blood Pressure Control | BP and HR of volunteers were measured before and immediately after VM. | Why does blood pressure fluctuate? | Blood pressure oscillates with the breath. | Understand the control of arterial pressure, focusing on the respiratory rate. Study the anatomical and physiological effects of mechanical ventilation on arterial pressure. |
| 1.1.3. Homeostasis and Temperature | BT, HR, and RF of volunteers, as well as AT and RH, were measured three times a day, in the morning (8:00 AM), afternoon (1:00 PM), and evening (7:00 PM). | What happens to the respiratory frequency in humans when ambient temperature and atmospheric humidity increase? | In situations of increased ambient air temperature and humidity, there is an increase in the respiratory rate, which contributes to the maintenance of body temperature in humans. | Understand the thermoregulatory response in humans and correlate with dark/light cycles. |

AT, atmospheric temperature (°C); BP, blood pressure (mmHg); BT, body temperature (°C); HR, heart rate (beats/min); RF, respiratory frequency (counts/min); RH, relative humidity (%); VM, Valsalva maneuver.

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voluntarily participating in the work and had presented medical certificates for physical activity (Table 1, no. 1.2). Specifically, for the project, “Homeostatic Blood Pressure Control” (Table 1, no. 1.1.2), the students applied the practical laboratory class described by literature (5), employing the Valsalva maneuver breathing technique, which can be used to help diagnose problems related to the autonomic nervous system and baroreflex control (13).

5) Scientific Divulgation: At the end of the classes, dissemination of the results was achieved by conducting public seminars and elaborating articles and posters. At the end of the course, to evaluate the success of the methodology (research-based teaching), reading circles were held in the classroom to discuss its positive and negative impacts.

RESULTS AND DISCUSSION

The results were presented by a total of eight groups, with four in the class of the 2017 semester and four in the class of the 2018 semester. All the groups chose to use experimental research for data collection. Table 1 describes some of the projects developed by the students, which included bibliographic research as well as environmental and biological measurements (temperature, BP, HR, respiratory frequency, and others).

Active learning is characterized by a student-centered approach to learning and teaching, where teachers are seen as facilitators of learning. It consists of a broad range of pedagogical procedures, including research-based learning, intended to stimulate the learner’s critical thinking skills (4). Work reported in the literature indicates that the active learning approach to physiology teaching is more effective than passive approaches (11). In the present work, active learning by research was introduced into traditional teaching of homeostasis, as a tool that could help the student to contemplate the complexity of the concepts and mechanisms involved in maintaining the internal body environment. A student-centered learning environment is one in which attention is focused on what the students are doing, with the students’ behavior being the significant determinant of what is learned (11). It is acknowledged that the role of the teacher matters greatly (after all, it is the teacher who designs and implements the learning environment), but the attention here is firmly on the students.

Compared with a standard lesson, where the lecturer shows several static images and relies on them to explain key concepts, the research-based, teaching-learning method applied to human physiology can be much more effective, going beyond the simple handling of equipment and glassware. It is important that the students should make connections between the activity in question and the correlated conceptual knowledge, responding to questions raised, creating research topics, evaluating the literature, writing research proposals, generating data, and analyzing new and preexisting data.

In the present study, the students were able to express their difficulties during this process, as well as to give their views about the contribution of research-based teaching of physiology. Unlike a demonstration in which the teacher does everything and the students observe, priorities in experimental activities are that the students should not only undertake the steps of the experiment, but also propose the techniques required to perform the tests or to solve a certain problem. This type of investigation requires the engagement of the students, exchange of ideas, elaboration of explanatory hypotheses, and the performing of appropriate experimental tests (2, 3). Therefore, as in the present study, the use of research-based teaching can increase the commitment and collaboration of the student during the teaching-learning process.

As an innovation in the discipline, the groups had the opportunity to choose the subjects to be addressed and to study them in a participatory, integrative, and engaged way. Importantly, all of the students were able to develop all of the stages of a research project, as well as to properly evaluate the results obtained after application of the experimental procedures, associating them with the basic mechanisms of maintenance of body homeostasis and integrating concepts of anatomy, physiology, biochemistry, and pathology. Following this successful activity, some students who excelled during the course were invited to disseminate their research projects in other classes.

In addition, the didactic materials compiled by the students during the work, including reports, portfolios, and seminar materials, were shared voluntarily among the groups, hence replicating and amplifying the creation of knowledge. Considering the good acceptance, motivation, and commitment of the students, the technique of teaching through research will be adopted in other disciplines for the study of diverse contents and courses, not only physiology.

The present study describes the methodology, characteristics, and applicability of research-based teaching in the classroom, together with the perception of a university lecturer regarding its use, in the light of studies reported in the literature. The perception of the students regarding this methodology seemed to be positive, since, at the end of the classes, they verbally approved and widely affirmed the positive value of this educational tool. However, future studies will be required to systematically evaluate the perceptions of students concerning research-based teaching, as well as the impact of using this teaching methodology on effective student learning regarding the contents of human physiology.

In conclusion, the adoption of a research-based methodology provided opportunities for the students, through active learning, to relate the theoretical contents learned in the classroom to those applied in the practical activities, hence making the learning process more meaningful. In addition, the students had the opportunity to acquire leadership attributes and to work in teams as effective researchers and organizers. The experience aroused the interest of the students in searching for knowledge of the causes of phenomena in the normal state of the body (in other words, physiology), contributing to improving the future performance of the students as health professionals. The results of the present work demonstrate the potential effectiveness of inclusion of the research-based teaching approach in innovative educational programs, including research and extension activities related to physiology.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author.
AUTHOR CONTRIBUTIONS

E.M.G. conceived and designed research; performed experiments; analyzed data; interpreted results of experiments; drafted manuscript; edited and revised manuscript; approved final version of manuscript.

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