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## The case of thyroid hormones: how to learn physiology by solving a detective case

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**Lellis-Santos C, Giannocco G, Nunes MT.** The case of thyroid hormones: how to learn physiology by solving a detective case. *Adv Physiol Educ* 35: 219–226, 2011; doi:10.1152/advan.00135.2010.—Thyroid diseases are prevalent among endocrine disorders, and careful evaluation of patients' symptoms is a very important part in their diagnosis. Developing new pedagogical strategies, such as problem-based learning (PBL), is extremely important to stimulate and encourage medical and biomedical students to learn thyroid physiology and identify the signs and symptoms of thyroid dysfunction. The present study aimed to create a new pedagogical approach to build deep knowledge about hypo-/hyperthyroidism by proposing a hands-on activity based on a detective case, using alternative materials in place of laboratory animals. After receiving a description of a criminal story involving changes in thyroid hormone economy, students collected data from clues, such as body weight, mesenteric vascularization, visceral fat, heart and thyroid size, heart rate, and thyroid-stimulating hormone serum concentration to solve the case. Nevertheless, there was one missing clue for each panel of data. Four different materials were proposed to perform the same practical lesson. Animals, pictures, small stuffed toy rats, and illustrations were all effective to promote learning, and the detective case context was considered by students as inviting and stimulating. The activity can be easily performed independently of the institution's purchasing power. The practical lesson stimulated the scientific method of data collection and organization, discussion, and review of thyroid hormone actions to solve the case. Hence, this activity provides a new strategy and alternative materials to teach without animal euthanization.

thyroid hormone actions; hypothyroidism; hyperthyroidism; practical lesson; problem-based learning

PHYSIOLOGY EDUCATION is present in the majority of biomedical science courses. Particularly, endocrine physiology education generates difficulties in attracting students because, among other reasons, it requires a background in biochemistry, cell biology, and general and systems physiology in addition to the ability to connect and relate these knowledge aspects to one another (23).

Diverse educational strategies have been used in biomedical science courses to improve the process of teaching and learning. These include problem-based learning (PBL), concept maps, hands-on activities, computer laboratory activities, practical lessons, PubMed literature searches, and other types of activity to get the students actively engaged, which has been shown to be an essential point for "meaningful learning" (10).

PBL is a pedagogy in which the problem becomes the stimulus for the learning experience; it has been used as a method for teaching (and learning) since the 1980s, and it is considered a major educational method to teach endocrine

physiology (1). Besides improving technical vocabulary (4), this didactic resource involves identifying concepts, selecting them by importance, and finding hierarchical relations among them; furthermore, it is a type of meaningful learning (14), and using this strategy to solve a detective case related to thyroid hormone effects could be a useful tool.

Thyroid dysfunction is prevalent among endocrine disorders. In the United States, hypothyroidism is present in 4.6% of the population (clinical: 0.3% and subclinical: 4.3%) and hyperthyroidism is present in 1.3% of the population (clinical: 0.5% and subclinical: 0.7%). A long-term study (21) in the United Kingdom reported that the incidence of hyperthyroidism is 0.8:1,000 women/yr and hypothyroidism is 3.5:1,000 women/yr (21). In Brazil, the data indicate that the prevalence of hypothyroidism is 12.3% (6.9% in black, 8.8% in mulatto, and 16.7% among white women) (19) and hyperthyroidism is ~5% (6% in women of 50–59 yr old, 5% in women of 60–69 yr old, and 3.8% in women of 70–79 yr old) (2).

The terms "hyperthyroidism" and "thyrotoxicosis" are often used interchangeably, irrespective of whether the disorder is caused by the endogenous overproduction or excessive ingestion of thyroid hormones. The causes of hyperthyroidism include Graves disease, multinodular goiter, an autonomously functioning single thyroid nodule (adenoma), thyroiditis, functioning thyroid carcinoma, factitious hyperthyroidism (caused by excessive intake of thyroid hormone medication), etc. The most common cause of hypothyroidism is the primary failure of the thyroid gland, whereas secondary or tertiary hypothyroidism, which results from pituitary or hypothalamic dysfunction, is rare. The possible causes of hypothyroidism are Hashimoto's disease, thyroidectomy, and amiodarone-induced and iodine deficiency disease (21). Besides those nomenclatures, it is necessary that the students understand how thyroid dysfunction can be diagnosed by symptomatology analysis.

The present article proposes a didactic strategy to teach and learn the metabolic and systemic dysfunction resultant from hypo- or hyperthyroidism induction in rats by means of a PBL activity. By solving a detective case, students are stimulated to reason and integrate collected data to determine results. Some information (clues) is not shown to the students, which permits them to reflect on what they have learned on thyroid gland physiology classes, to assimilate new information discussed in groups, and to critically evaluate the results obtained. In addition, we propose different resources that can be used to perform this practical lesson in different places (university, college, high school, congress, or meeting exposition) despite the purchasing power of the institution. Moreover, we suggest the use of small stuffed toy animals, drawings, and photographs, instead of experimental animals, as an alternative educational method for carrying out practical lessons.

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## MATERIALS AND METHODS

The practical lesson is based on a detective case, in which some data related to the three possible conditions of thyroid functional states (euthyroidism, hypothyroidism, and hyperthyroidism) are supplied, whereas other data are omitted. Therefore, students are stimulated to organize, make correlations, and interpret the data as well as formulate hypothesis to identify the three conditions elected for this activity, i.e., they have to collect all information to be capable of solving the case. The practical lesson guidelines can be adapted for each institution regarding the availability of material.

The following case vignette was used in an endocrinology practical lesson about thyroid hormone actions for undergraduate students from the Physical Education and Sports Course at the University of São Paulo (São Paulo, Brazil). It was named "The Case of Thyroid Hormones."

*"The Case Of Thyroid Hormones"*

"In the still of a night, a citizen, wearing suspicious clothes, invaded the building of the Institute of Biomedical Sciences of the University of São Paulo. Weeks later, some animals of the rat vivarium underwent changes in behavior and, particularly, in some morphological, physiological, and biochemical parameters. Some witnesses affirmed that they saw the mysterious citizen injecting substances in those rats. The data collected by scientific police accused three different substances: one that does not modify, one that increases, and another one that decreases the plasma thyroid hormone concentration. Students of the Department of Physiology and Biophysics of the University of São Paulo commit themselves to solve the case. They started working to identify into which rats (*rats 1, 2, or 3*) the respective substances had been injected."

Students were sorted into groups and received the practical lesson guideline and a chart to fill out (Table 1). To observe and collect data presented about the victims (rats), they analyzed different evidence displayed on benches, being guided by monitors. However, there were some missing data, represented by "?" symbols.

In the present article, we used different material to execute the same practical lesson, and the purpose was that the activity could be offered elsewhere, independently of the purchasing power of the institution worldwide.

Moreover, it could replace the use of animals in practical lessons, even though one of the possibilities presented here is to show clues derived from animals treated with different substances, as it explained below. To take advantage of the rats that were subjected to the treatments, after rats had been anesthetized, parts of their body, as the thyroid gland, heart, and abdomen, were photographed. Thus, the images can be used for future practical lessons, preventing further animal euthanizations.

Beyond working with photographs, the use of original illustrations or drawings taken from authorized sites from the internet is also possible. Moreover, the collection of small stuffed toy rats, of differ-

ent sizes/weights, and organs made from play dough simulating the desired conditions are another method to perform the practical lesson in a playful learning environment.

The monitors must be prepared to give information about the clues and to stimulate students to find out their significance. Hence, they act as mediators, helping students to interpret the data and solve the case, without giving the answer. Monitors must be impartial, and the terms "hypothyroidism" and "hyperthyroidism" are prohibited in the information provided.

*Procedures*

*Animal treatment.* Male Wistar rats (250 g) were subjected to different manipulations of thyroid status. *Rat 1* was treated with triiodothyronine ( $T_3$ ; Sigma Chemical, St. Louis, MO) at a dose of 100  $\mu\text{g}/100\text{ g}$  body wt ip, twice daily, for 1 wk, to induce the hyperthyroid state. *Rat 2* was treated with 0.03% methylmercaptimidazole (MMI; Sigma Chemical), which was added to drinking water for 10 days. This drug blocks thyroid hormone synthesis, causing, therefore, a hypothyroid state. *Rat 3* was treated with 0.9% NaCl (saline) and was used as a control. After the specified periods, rats were weighed and anesthetized with ketamine and xylazine (100 and 10 mg/kg body wt, respectively), and specific internal organs were exposed and photographed. The photographs were presented to the students, who compared the thyroid gland and heart size, visceral fat content, mesenteric vascularization, body weight, etc. and used the data obtained to solve the case.

Animals were killed by decapitation afterward. The animal facilities and manipulation met the guidelines of the Brazilian College of Animal Experimentation, and the protocol was approved by the Institute of Biomedical Sciences/University of São Paulo Ethical Committee for Animal Research.

*Working with photos.* As specified above, some organs/tissues of the animals, such as the thyroid gland, heart, visceral fat, and mesenteric vascularization, were exposed and photographed (Fig. 1). The purpose of obtaining the images is that they can be used for future practical lessons, preventing further animal euthanizations. Rats were photographed while being weighed in a balance to provide a representation of registering the effects of the substances injected on body weight. The heart rate and thyroid-stimulating hormone (TSH) serum concentration data can be supplied by a fictitious ECG and radioimmunoassay, respectively.

*Working with small stuffed toy rats.* Another form to replace the use of the animals in the practical lesson is to use small stuffed toy rats (plush rat) and play dough made organs. Plush rats were given an opening in the abdomen to allow the visualization of the thoracic box and abdominal cavity. For analysis of the animal's body weight, bean-filled bags were added in the abdomen opening to reach the desired weight (239 and 250 g for *rats 2* and *3*, respectively). Another type of material can be used to reach the desired weight. To provide different degrees of mesenteric vascularization, blood vessels were drawn in varied numbers and ramifications on clear flexible plastic, which was placed inside the abdominal cavity. The visceral body fat can be drawn on the plastic, as specified for the blood vessels, or represented adding diverse amounts of styrofoam flakes to the abdominal cavity. The heart and thyroid were molded in play dough to simulate different sizes of the organs, corresponding to the desired situations (Fig. 2). Data of the heart rate and serum TSH levels can be supplied by a fictitious ECG and radioimmunoassay, respectively.

*Working with illustrations.* This practical lesson can also be performed through the use of drawings taken from authorized sites from the internet or prepared by the students, teacher, or monitors. The drawings must illustrate the organs and structures in different sizes so that the thyroid functional states can be recognized (Fig. 3). Note that the different drawings were presented in a fixed size paper but that the magnitude of the organs was modified regarding the expected rat condition. The body weight clue could be represented by a rat being weighed, mesenteric vascularization by an amplified section of abdominal cavity, visceral body fat by an abdominal positron emission

Table 1. Chart provided at the beginning of the activity to record the data

Evidence	Victims		
	<i>Rat 1</i>	<i>Rat 2</i>	<i>Rat 3</i>
Body weight	?		
Mesenteric vascularization			?
Visceral body fat		?	
Heart size		?	
Thyroid size			?
Heart rate	?		
Serum thyroid-stimulating hormone concentration	?		

"?" symbols indicate missing data.

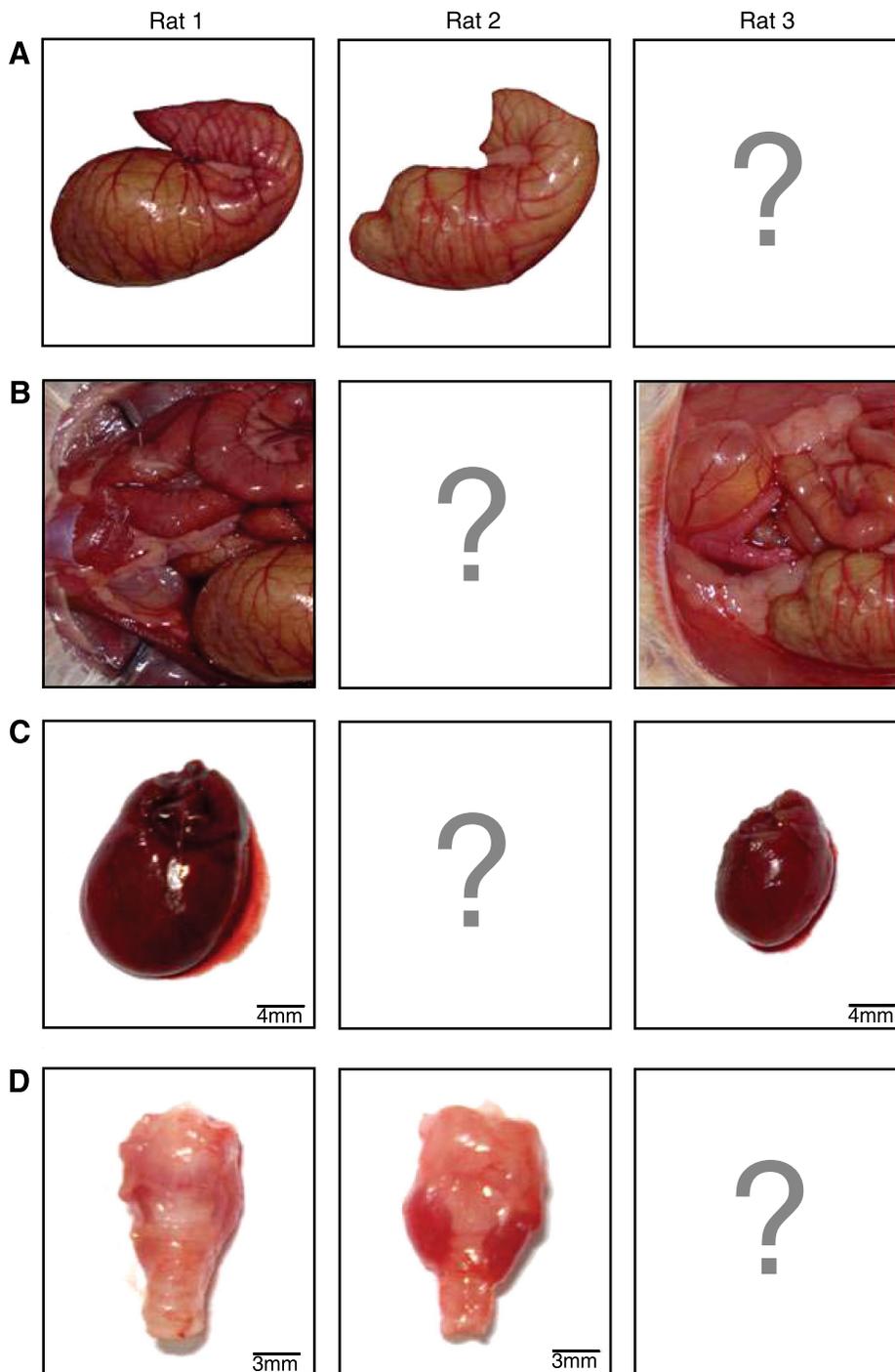


Fig. 1. Working with photos. One week after treatment with different drugs, rats were euthanized, and representative pictures were taken of specific organs and regions. *A*: mesenteric vascularization, as represented by intestine pictures, demonstrating the different levels of blood vessel proliferation. *B*: pictures of the lower abdominal cavity with different visceral body fat content. *C* and *D*: pictures of the heart (*C*) and thyroid (*D*) isolated from the body to allow a size comparison. Note that scale bars are shown in the pictures. Heart scale bar = 4 mm; thyroid scale bar = 3 mm.

tomography scan, heart and thyroid sizes by different images, and heart rate and TSH serum concentration by suggested values.

## RESULTS

### *Solving the Case*

After collecting the data, students filled out the chart, as shown in Table 2. As pointed out above, one piece of the information was omitted; thus, comparisons had to be made between the parameters of only two rats. Students had to collect all of the clues and integrate the diverse possibilities

of the missing clues. This allowed the students to solve the case only after the whole amount of data was obtained.

The solution of the problem shows that the *rat 1* received a substance that increased the thyroid hormone plasma concentration, *rat 2* received a substance that decreased the thyroid hormone plasma concentration, and *rat 3* received a substance that did not affect the thyroid status.

*Clue 1: body weight.* The information about the animals' body weight is not essential for the resolution of the case. In fact, if it is analyzed individually, it can generate a controversial interpretation.

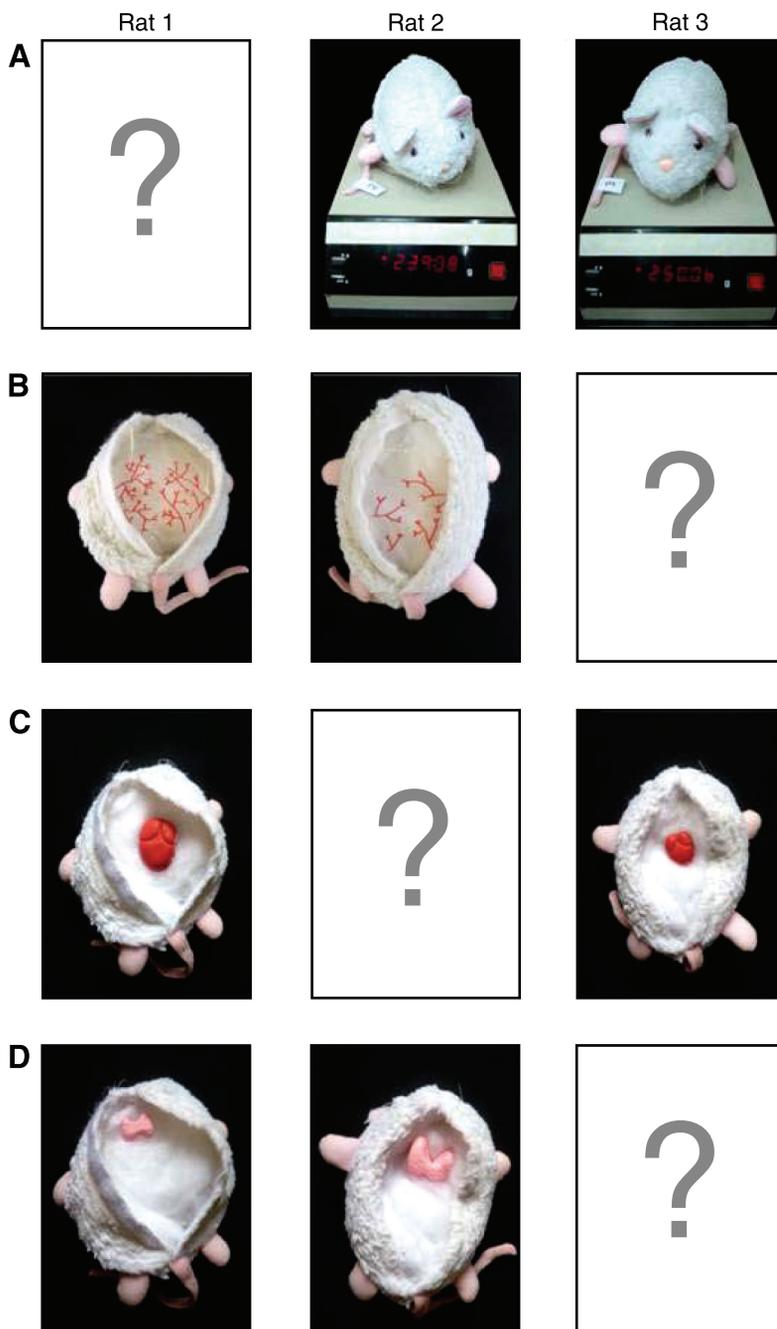


Fig. 2. Working with small stuffed rats. Small stuffed rats were collected to avoid animal euthanization and to make the activity more enjoyable. *A*: bean-filled bags were added inside the opening in the rat abdomen to reach the desired weights. *B*: blood vessels were drawn on clear flexible plastic inside the abdomen to simulate the different levels of vascularization. *C* and *D*: different sizes of the heart (*C*) and thyroid (*D*) were sculpted in play dough and placed in the ventral opening of the rats.

In the beginning of the practical lesson, students were informed that before manipulation of the rats by the mysterious person, they weighed  $\sim 241$  g, and that among the three rats, *rat 1* had disappeared. Thus, it was observed that *rat 2* had a slight reduction in body weight (239 g) during treatment, and *rat 3* presented an increase in body weight (250 g) (Figs. 2A and 3A). During normal development of an animal, it is expected that it gains weight; if it loses weight, it seems that something abnormal could be occurring. Considering that thyroid hormone increases energy expenditure and heat production, we can infer that the reduction of body weight could result from a hyperthyroid state (20). However, in situations in which thyroid hormone actions are decreased, for instance, when thyroid hormone synthesis is blocked, a body weight reduction

can be observed as well, since growth hormone synthesis and secretion are upregulated by thyroid hormones (7, 11).

*Clue 2: mesenteric vascularization. Rat 3 was missing.*

It was observed that the mesenteric vascularization of *rat 1* was larger than that of *rat 2* (Figs. 1A, 2B, and 3B). As pointed out above, thyroid hormone increases energy expenditure. Thus,  $O_2$  consumption as well as  $CO_2$  and heat production are increased.  $CO_2$  and heat are potent vasodilators, which lead us to expect higher vascularization in hyperthyroid states. Moreover, it has been demonstrated that VEGF expression, which stimulates the growth of new blood vessels, is increased by thyroid hormones (5). Thus, for the students (detectives), *rat 1* seems to present a higher thyroid hormone plasma concentration, at least compared with *rat 2*.

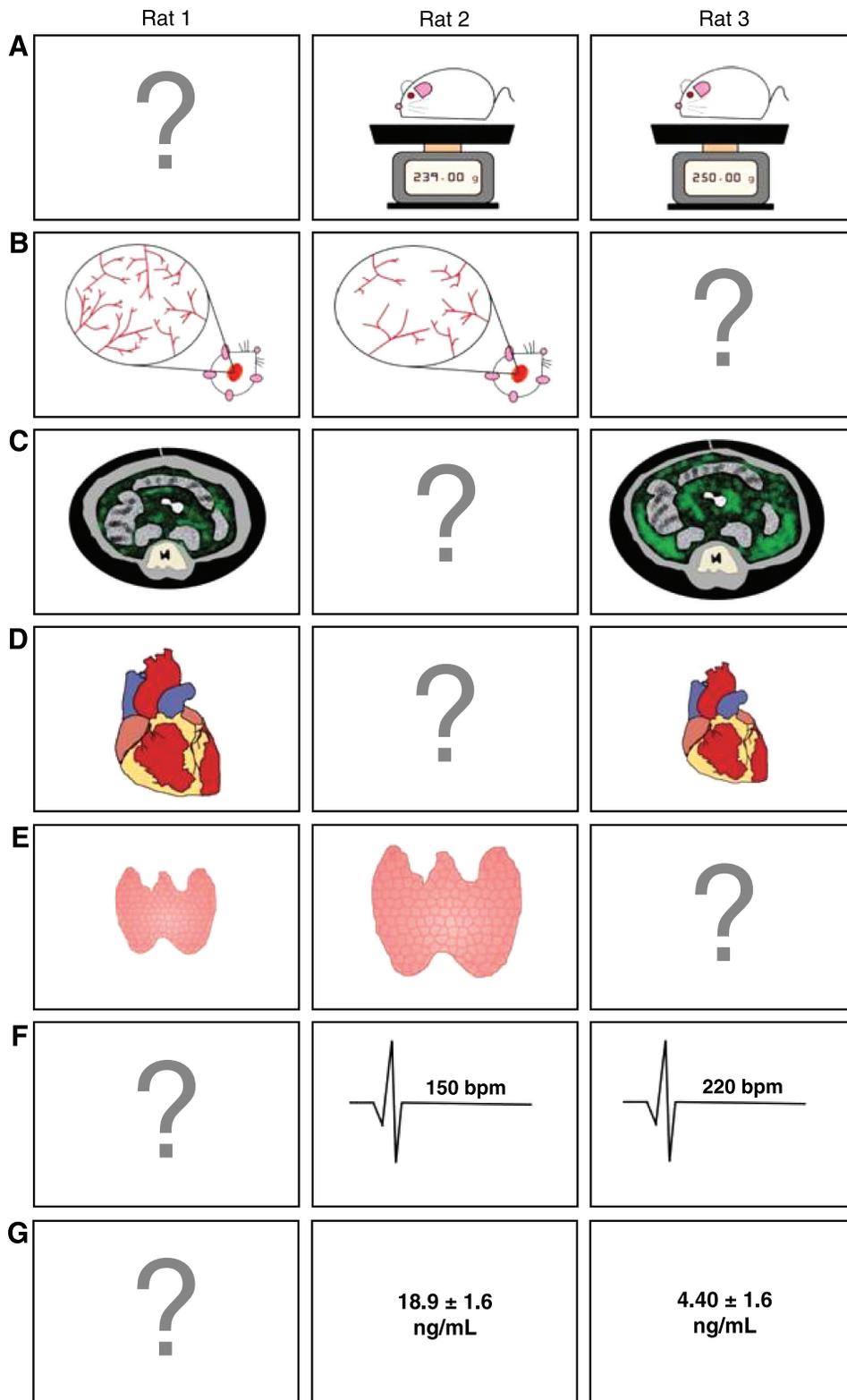


Fig. 3. Working with illustrations. Different illustrations were created to simulate the specific conditions. *A*: body weights were represented by the rat being weighed. *B*: mesenteric vascularization was represented by zoomed views of peritoneal sections. *C*: abdominal positron emission spectroscopy scans were drawn to show the different levels of visceral fat accumulation. *D* and *E*: different sizes of the heart (*D*) or thyroid (*E*) were represented by alterations of the image sizes. *F* and *G*: values of the heart rate [in beats/min (bpm); *F*] and serum thyroid-stimulating hormone concentration (*G*) were provided.

*Clue 3: visceral body fat. Rat 2 was missing.*

It was observed that *rat 1* had much less visceral body fat than *rat 3* (Figs. 1*B* and 3*C*), which seems to indicate that lipid metabolism was enhanced in *rat 1*. Thyroid hormones are known to induce white adipose tissue differentiation, lipogenic enzyme expression, intracellular lipid accumula-

tion, and adipocyte proliferation (3, 13, 15). They also increase  $\beta$ -adrenergic receptor expression in white adipose tissue, making adipocytes more sensitive to catecholamines, which are known to exert a lipolytic effect (6, 22). They also decrease phosphodiesterase activity, resulting in increased cAMP levels and hormone-sensitive lipase activity (8).

Table 2. Filled-in chart

Evidence	Victims		
	Rat 1	Rat 2	Rat 3
Body weight, g	?	239	250
Mesenteric vascularization	↑	↓	?
Visceral body fat	↓	?	↑
Heart size	↑	?	↓
Thyroid size	↓	↑	?
Heart rate, beats/min	?	150	220
Serum thyroid-stimulating hormone concentration	?	↑	↓

Symbols represent increases (↑) and decreases (↓) based on pair similes.

Thus, this clue also points to *rat 1* being subjected to a hyperthyroid state.

*Clue 4: heart size.* *Rat 3* was missing.

The heart size of *rat 1* was bigger than that of *rat 2* (Figs. 1C, 2C, and 3D). It could be inferred that the heart of *rat 1* was working harder than that of *rat 2*. One possibility is that a substance caused heart hypertrophy in *rat 1* or heart atrophy in *rat 2*.

Alterations in cardiovascular function are due to increased circulatory demands that result from hypermetabolism and the need to dissipate the excess of heat production (24). Moreover, thyroid hormones cause cardiac inotropic effects by inducing the expression of  $\alpha$ -myosin heavy chain contractile protein, which would increase cardiac output. Furthermore, the increased heat production would decrease systemic vascular resistance (9). These results are compatible with a hyperthyroid state.

*Clue 5: thyroid size.* Thyrotropin, or TSH, is the major regulator of thyroid gland function and morphology (17, 18). Thus, the increase in thyroid gland size observed in *rat 2* could indicate that it is under high-TSH stimulus, i.e., the plasma TSH concentration is increased. The smaller thyroid gland of *rat 1* could indicate that the plasma TSH concentration was decreased compared with *rat 2* (Figs. 1D, 2D, and 3E). Thus, it can be inferred that *rat 1* might have higher plasma thyroid hormone concentrations, which, by negative feedback, would decrease TSH.

Thus, all the evidence presented up to this point, such as increased mesenteric vascularization, decreased visceral body fat, increased heart size, and decreased thyroid gland size, indicate that *rat 1* received a substance that increased thyroid hormone concentration in the plasma. Now, we have to indentify between *rats 2* and *3* which received the substance that decreased and which received the substance that did not modify the thyroid hormone concentration.

*Clue 6: heart rate.* Finally, even though the clue about the heart rate of *rat 1* had not been shown, it was considered that this rat had received the substance that increases the thyroid hormone concentration; therefore, the heart rate of *rat 1* would be  $>220$  beats/min (*rat 3*). In parallel to their inotropic effects, thyroid hormones are known to promote chronotropic effects by inducing the expression of HCN2 and HCN4 proteins, which are responsible for the pacemaker activity of the sinus node (9). Thus, it is expected that the heart of the rat exhibits tachycardia in response to the thyroid hormone excess. *Rat 2* presented a lower heart rate compared with *rat 3* (Fig. 3F), which means that it presented a decrease in plasma thyroid

hormone levels. Thus, the decrease of stroke volume and heart rate reflects the reduced inotropic and chronotropic effects of thyroid hormones (9). The data presented strongly indicate that *rat 2* received the substance that decreased thyroid hormone concentration.

*Clue 7: TSH serum concentration.* This clue led us to confirm the hypothesis that *rat 2* was the one who was treated with a substance that decreased plasma thyroid hormone concentration, since it presented a 4.3-fold increase in TSH serum levels compared with *rat 3* (Fig. 3G).

TSH is a member of the glycoprotein hormone family and consists of two subunits,  $\alpha$  and  $\beta$ , that are encoded by distinct genes on different chromosomes. The  $\alpha$ -subunit is shared by all members of the glycoprotein hormone family, including luteinizing hormone, follicle-stimulating hormone, and chorionic gonadotropin, in addition to TSH. The  $\alpha$ -subunit gene is, therefore, expressed in three distinct cell types: thyrotrope and gonadotrope cells of the anterior pituitary and trophoblast cells of the placenta. In contrast, expression of the  $\beta$ -subunit of TSH is restricted to thyrotrope cells (17, 18). Thyroid hormone decreases the expression of the  $\beta$ -subunit of TSH (25) and the TSH serum concentration. On the other hand, TSH levels are increased in hypothyroid rats compared with control rats ( $18.9 \pm 1.6$  vs.  $4.40 \pm 0.9$  ng/ml) (16). This piece of information, associated with the bradycardia observed in *rat 2*, allows us to conclude that *rat 2* received the substance that decreased thyroid hormone concentration. Thus, the clues presented led us to conclude that *rat 3* represents the control animal, the one that received the solution that did not modify thyroid hormone concentration.

## DISCUSSION

The hands-on activities are important to complement the content learned during the graduation and postgraduation courses and to develop critical thinking. To attain these purposes, living animals have been used in practical lessons for a long period of time and are considered as a good strategy in many curricula. However, educational and research institutions have been under pressure from animal protective societies, which have been working to reduce or even to forbid the use of animals in research and learning. Furthermore, it is highly recommended that alternative strategies that permit the development of the critical thinking and avoid the use of living animals could be offered.

Many approaches have been developed to integrate traditional education with new methods of learning, some of them with the help of technological tools, such as specific software, that have been largely used in many fields of knowledge, including physiology of the organs and systems. Even though these programs are very important for learning, in general, the responses that are obtained using this methodology are highly predictable, preventing us from identify responses that are not expected and that currently occur when living organisms are used in practical activities. Thus, although they might help the process of learning, they preclude us from understanding that each living organism is unique and could respond to the same stimulus in a different way. Moreover, digital technology might not be available to all segments of the population, due to economic and geographic limitations.

The present study was intended to provide some possibilities to teach and learn thyroid gland physiology by means of a practical lesson using a pedagogical strategy, which was developed to motivate students to solve a detective case using clues that are presented during the activity.

Although this lesson was originally designed and carried out using laboratory animals, the use of different resources (photos, drawings, and small stuffed toy rats) to demonstrate the effects of thyroid hormones might properly replace the use of living animals. The original thyroid practical lesson had been performed for 15 yr by a single professor; many animals were euthanized, and the only tissue presented to the students was the thyroid gland. Briefly, the class only focused on showing to the students the alterations in thyroid morphology after the same three different treatments described in this practical lesson. The simple exclusion of one clue, the missing clue, and the creation of a detective case provided active rather passive learning compared with the old-fashioned class. This strategy has been shown to be effective for learning, since it stimulates students to think, integrate, and revise the thyroid hormone physiology content learned in lectures, and it was very well accepted by the students. Moreover, this activity could be adapted to a PowerPoint presentation, which could be more effective for a class with a large number of students.

This activity is also a PBL exercise, since students have to collect information about the conditions of the rats without knowing about which thyroid status alterations the rats were subjected to. Students also have to organize the evidence and to deduce the missing clue by integrating previous knowledge of thyroid hormone actions and regulation.

Therefore, this lesson goes beyond conventional classes parameters, becoming a new strategy able to provide a meaningful learning experience. The evidence could be well integrated with previous knowledge, and it is accompanied by the building of multiple representations (mental models) connected to many other phenomena (12).

Another positive and common aspect of this practical lesson is the group work/discussion. After checking the clues displayed on the benches, the students argue about the evidence and try to elucidate the case. This discussion time is essential to allow students to compare the collected notes of the group as well as to understand how important the personal previous knowledge is to optimize the process of case solving.

The content of endocrine physiology is extensive, and few students are able to assimilate all the information taught in lectures. However, contributions from each group member allow the case to be easily solved, and the group discussion encourages students learn with their classmates. In contrast to the majority of adopted practical lessons in physiology courses, which demand a large amount of material in a restricted time, this activity can be addressed to short or long periods, depending on the specific purposes. As we have observed during the largest Brazilian meeting on experimental biology, 30 min were enough for the participants to collect the clues, integrate the evidence, and solve the case. However, the professor can increase the degree of complexity of the lesson by discussing physiological alterations caused by thyroid hormones on other systems, scientific methodology and data collection, and diagnostic methods, techniques, and analyses of data (positive emission tomography scan, Western blot analysis, ECG, radioimmunoassay), as we performed during 2 h to students of a

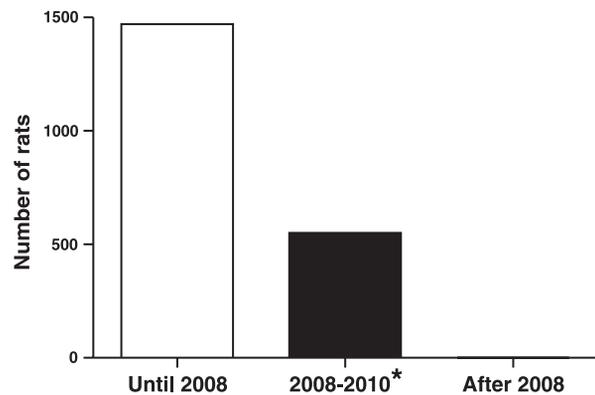


Fig. 4. Numbers of rats euthanized in the thyroid practical lesson. The open bar shows the number of rats euthanized during 16 yr, in which the traditional practical lesson on thyroid gland physiology was carried out. The solid bar shows the estimated number of rats (~550 rats) that would be euthanized to perform the same practical lesson in the period of 2008–2010, taking into account that more professors included the thyroid practical lesson in their curriculum. After 2008, when this hands-on activity was created, rat euthanization was completely abolished in the thyroid physiology classes. \*Predicted number.

physical education course. Another positive aspect of this lesson is the possibility of being it performed in any institution independent of its purchasing power. Using proper resources (photos, drawings, or small stuffed toy rats), this lesson can be applied in workshops, meetings, symposiums, and congresses.

According to saving animal principles, this practical lesson promoted an environment where professors from different parts of the country were allowed to include a hands-on thyroid activity in their physiology curriculum, since laboratory animals were no longer necessary. Over 16 yr, the practical lesson euthanized ~1,470 rats to perform the activity in the Physical Education and Nutrition course of the University of São Paulo. If this practice was maintained from 2008 up to 2010, it would have been necessary to kill 550 rats to attain the practical lesson. Nevertheless, the use of the alternative materials abrogated animal euthanization since 2008 (Fig. 4).

Therefore, this article presents an alternative pedagogical method for teaching students in physiological courses that is more enjoyable and attractive and provides an effective tool to optimize knowledge acquisition by the students, helping lectures to improve classical classes. In addition, this hands-on activity can help educational institutions avoid the use of animals in practical lessons. Moreover, thyroid diseases represent a worldwide public health problem and are currently the targets of many research groups and governmental investments. Thus, the development of pedagogical strategies to improve the learning of thyroid pathophysiology would provide an important tool for teaching in biomedical courses.

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#### DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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