HOW WE TEACH | Classroom and Laboratory Research Projects

The use of the "Endocrine Circuit" as an active learning methodology to aid in the understanding of the human endocrine system

Lucas Zangerolamo,* Gabriela Moreira Soares,* Lucas Rodolfo de Oliveira Rosa, Karina Rodrigues Santos, Gabriela Alves Bronczek, Emílio Marconato-Júnior, Everardo Magalhães Carneiro, and [®] Helena Cristina de Lima Barbosa-Sampaio Department of Structural and Functional Biology, Obesity and Comorbidities Research Center, Institute of Biology, University of Campinas, Campinas, São Paulo, Brazil

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Zangerolamo L, Soares GM, Rosa LR, Santos KR, Bronczek GA, Marconato-Júnior EM, Carneiro EM, Barbosa-Sampaio HC. The use of the "Endocrine Circuit" as an active learning methodology to aid in the understanding of the human endocrine system. Adv Physiol Educ 44: 124-130, 2020; doi:10.1152/advan.00123.2019.-The search for more efficient teaching methodologies is a great challenge for Brazilian educators, since most classes are still traditional (theoretical) and have little student involvement during the learning process. Active learning methodologies, where students play a central role in the learning process, are proving to be more effective and interesting when it comes to acquiring knowledge. Thus we decided to develop an innovative technique for teaching Human Endocrine Physiology, called "Endocrine Circuit." The circuit consisted of eight stations in which students were asked to organize a scheme with cards to answer a specific question about a gland or tissue with endocrine relevance. The effectiveness of the developed activity was validated through a pretest-posttest design, in which the students had to answer a 10-question test. We found out that, after the Endocrine Circuit application, students showed an improvement in the percentage of correct answers for 7 out of 10 questions contained in the questionnaire ($P \le 0.05$). In addition, the activity showed positive outcomes regarding student's engagement in this study, besides showing to be more efficient than the Brazilian traditional theoretical classes.

active learning; blended learning; educational intervention; physiology education; teaching methods; undergraduate courses

INTRODUCTION

The proper educational formation of undergraduates is essential for a well-functioning society. This is especially critical for students of biological and health science courses, as their activities shape public health and medical research (5). They also greatly influence public perception of health and science, as the population expects to be able to count on these professionals to relay accurate information regarding these subjects, especially at the present time, in which inaccurate information is so readily available online (10). This way, promoting the best learning context for these students is extremely important. Concerning classroom practices in Brazilian teaching centers, the most widespread method is still the traditional teachercentered approach (1), in which a teacher provides information about a specific subject, and students listen and have minimal influence on the learning process (7). Even though this method is effective and has its place, it also has flaws; a study by Benware and Deci (2) evaluated students who learned through either a passive or an active orientation. Although both student groups achieved similar rote-learning scores, the group that received an active orientation showed higher conceptual learning scores and felt highly motivated and engaged with the material (2). Other studies have also reinforced that active learning strategies improve students' engagement and interest in comparison with passive learning strategies, even when dealing with complex topics (8).

Therefore, it is desirable to develop innovative teaching strategies that promote students being more active, effective, and engaging in the learning processes, and that is possible by making use of playful and interactive approaches (9). Thus we decided to develop a methodological strategy called "Endocrine Circuit," a complementary activity to the Endocrine Physiology classes, in which students were asked to answer specific questions about a gland or a tissue with endocrine relevance by organizing and working with a set of cards. We applied this teaching method for undergraduate students during Human Physiology classes and evaluated its effectiveness on the students' learning through a pretest-posttest design. We found out that, after the Endocrine Circuit application, students had an increase in the percentage of correct answers for 7 out of 10 questions contained in the test ($P \le 0.05$). In addition to that, both the activity acceptance by the students and their opinion about the efficiency of the Endocrine Circuit were positive, compared with those for the theoretical classes. The effectiveness of this active teaching methodology for teaching endocrine physiology is thus evident.

METHODS

Endocrine circuit: production, dynamic, and application. The Endocrine Circuit was developed as a complementary activity to the theoretical classes that compose the module of endocrinology in the class of Human Physiology offered by the Institute of Biology of the University of Campinas. The activity was performed after all of the theoretical classes of the endocrinology module.

This activity was composed of eight stations, which corresponded to eight questions about a gland or tissue with endocrine relevance.

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^{*}L. Zangerolamo and G. M. Soares contributed equally to this work.

Address for reprint requests and other correspondence: H. C. de Lima Barbosa-Sampaio, Obesity and Comorbidities Research Center, Institute of Biology, University of Campinas, UNICAMP. P.O. Box 6109, Barao Geraldo, Campinas, SP. CEP: 13083-865, Brazil (e-mail: bsampaio@unicamp.br).

These stations were developed based on the main subjects approached in the classes of Human Endocrine Physiology. The stations composing the Endocrine Circuit were as follows: 1) liver; 2) pancreatic islet; 3) adipose tissue; 4) skeletal muscle; 5) adrenal; 6) thyroid; 7) female reproductive system; and 8) male reproductive system (Fig. 1).

Each station had a main question to be answered (Fig. 1). To answer each question, students were expected to use the cards containing biochemical phenomena, hormones, and specific events related to the gland or tissue of the station; students also had to use arrows to indicate increase (\uparrow) or decrease (\downarrow) in the concentration of the hormones and biochemical phenomena in question. All of the cards and arrows were detailed in paperboard.

For the application of the Endocrine Circuit, students were divided into groups of five to seven, according to the number of enrolled students in each class. All of the stations were supervised by a member of our team (monitor) who coordinated time and helped the students formulate responses. Each group had a maximum of 15 min to formulate the answer using the available cards and provide the response to the monitor. We established expected responses for each station (Table 1); thus, when the response given by the group was incomplete, the monitor assisted the group with the reasoning for a correct answer. Therefore, all of the groups left the station knowing what the expected response in that station was. After 15 min, the groups changed to another station to respond to a new question, until

they all completed all of the eight stations. The time required for the application of this activity was 2 h.

The illustrations in the cards used in each station were acquired from Mind the Graph under Creative Commons Attribution-ShareAlike 4.0 International License, downloaded at www.mindthegraph. com

Research participants. The target audience of this activity was 62 undergraduate students of the Endocrine Physiology module in Human Physiology classes, offered at the Institute of Biology, University of Campinas. A consent form containing information about our research, as well as an agreement statement accepting anonymous participation, was signed by the participating students before the activity was carried out. All of the students who were present in the class participated in this study, which was characterized as a random assignment study. The Endocrine Circuit was conducted at the end of the Endocrine Physiology module. Thus the students were previously exposed to the topics approached in the circuit.

Student testing and data analysis. On the day of the activity, before the Endocrine Circuit, students answered a questionnaire containing 10 questions (Table 2) about subjects that would be approached in the stations. They were given 30 min to complete it. Immediately after the Endocrine Circuit, this questionnaire was reapplied. It is important to report that the students were not aware that a posttest would be administered. In addition, students also answered another question-

3- Adipose tissue



Fig. 1. Scheme of Endocrine Circuit stations. See Table 1 for a description of these stations.

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Fig. 1. -Continued

naire (Table 3) to gauge their perceptions and the contribution of the activity to their learning process. Results were analyzed using the parametric Student's *t* test, once data pass the normality test (Shapiro-Wilk test). The difference was considered statistically significant if $P \le 0.05$.

RESULTS

Questions performance. Table 4 shows the percentage of correct answers given for each question, before and after the Endocrine Circuit application. Students' scores for questions 3, 4, 6, 7, 8, 9, and 10 improved after the contact with the Endocrine Circuit. The greatest improvements, considering a higher percentage of correct answers after Endocrine Circuit application, were observed for questions 3 (36%), 4 (29%), 8 (29%), and 9 (42%). No difference in the percentage of correct answers was observed for questions 1, 2, and 5. Overall, students' performance on the quiz improved after the completion of the Endocrine Circuit, presenting a significant increase in the percentage of correct answers (Fig. 2).

Student interest and engagement. The Endocrine Circuit activity showed positive outcomes regarding student's engagement in this study (Fig. 3). When asked if the activity helped them to better understand the physiology of the endocrine system, 82.3% of the students said that it helped a lot, 14.5% replied that it helped, and 3.2% said that the activity partially helped (Fig. 3A). When the students were asked if they liked participating in the activity, 75.8% said that they liked it a lot, 21.0% said that they liked it, and 3.2% partially liked it (Fig. 3B). We also asked if they considered the activity more effective than a theoretical, expositive class: 87.1% said yes, 8.1% replied that they were indifferent, and 4.8% said no (Fig. 3C). Finally, we asked students to assign a number from 0 to 10 to the proposed activity, with 10 as the maximum score, and 98.4% assigned scores between 8 and 10 (Fig. 3D).

DISCUSSION

Our results show that the teaching method developed in this study is very effective in improving student's knowledge acquisition. The percentage of correct answers in the question-naire increased from 64 to 85.2% when comparing the pretest and posttest, an increase of 21.2%. The pretest-posttest design is widely used to test the effectiveness of educational approaches in the scientific literature (3, 4), which gives us confidence in the adequacy of our conclusions. Analyzing individually each question, seven questions showed improve-

	Table	1.	Expected	answers	for	each	station	of	^c the	Ena	locrine	Circu	ıit
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Station	Expected Answers
Liver	Relate the hormones with the biochemical phenomena that occur in the liver during fasting and fed states. In this station, students should be able to indicate what happens to the biochemical phenomena (gluconeogenesis and glycogenolysis) in the liver during fasting state (increase in gluconeogenesis and glycogenolysis, decrease in hepatic glycogen) and fed state (decrease in gluconeogenesis and glycogenolysis, favoring glycogenesis by increasing hepatic glycogen). In addition, they should be able to answer which hormones act in the two presented situations [fasting, predominant action of cortisol, glucagon, growth hormone (GH), and epinephrine; and fed, with predominant action of insulinl.
Pancreatic islet	How does the pancreatic islet respond to elevated plasma glucose?
	In this station, students should explain how the pancreatic islet responds to increased plasma glucose (increased glucose leads to the release and production of insulin by β -cells and decreased release and production of glucagon by α -cells). In addition, they should complement, indicating increased acetylcholine and muscarinic receptor activity and decreased epinephrine and α -adrenergic receptor activity.
Adipose tissue	Indicate the hormones that act on lipolysis and lipogenesis in adipose tissue. What are the effects of these hormones on cell adiposity?
	In this question, students should be able to identify the hormones involved in lipolysis (cortisol, glucagon, and epinephrine) and lipogenesis (insulin) and what the effects of these hormones are on cell adiposity (cortisol, glucagon, and epinephrine stimulate lipolysis by decreasing cell adiposity, while insulin stimulates lipogenesis and increase adiposity of the cell). In addition, they are expected to tell what the fluctuations in the concentrations of these hormones are in fasting and fed states (cortisol, glucagon, and epinephrine are increased during fasting and decreased in fed, and insulin is increased during fed and decreased in fasting).
Skeletal muscle	What happens in skeletal muscle during fasting and fed states? What are the effects of GH on this tissue? In this station, students should indicate what occurs in muscle tissue during fasting state [increase in free amino acids (proteolysis)] and in fed state (increase in protein synthesis). In addition, students should complement what the effects of GH on this tissue are (stimulation of proteolysis and glycogenolysis and decrease in protein synthesis during fasting state, and increase in protein synthesis in the fed state). In addition, cortisol and epinephrine concentration are increased in fasting. Cortisol favors proteolysis, and epinephrine acts to intensify the effects of cortisol
Adrenal	Identify the regions of the adrenal gland and their respective hormones. What are the effects of fasting on adrenal activity? In this question, the student is expected to identify the regions that compose the adrenal gland (cortex and medulla), as well as the hormones produced in each region [aldosterone, cortisol, and dehydroepiandrosterone (DHEAS) in the cortex, adrenaline and noradrenaline in the medulla]. Students are also expected to differentiate the stimuli involved in the production and release of hormones from the adrenal cortex and medulla (cortex is stimulated by the hypothalamic-pituitary-adrenal axis and the medulla by the sympathetic nerve). Students should also indicate that, during the fasting state, there is an increase in the production of corticotropin-releasing hormone (CRH) through the hypothalamus, which leads to the release of ACTH by the adophynophynois, resulting in the release of the hormones from the cortex.
Thyroid	What are the hormones produced by the thyroid gland? How do these hormones act on cell metabolism? What are the effects of cold on this gland? In this question, it is expected that the students identify the hormones produced by the thyroid gland (T3 and T4) and show the axis that regulates these hormones [thyrotropin-releasing hormone (TRH) released by the hypothalamus stimulates the production and release of thyroid-stimulating hormone (TSH) by the adenohypophysis, which will act in the thyroid gland, stimulating the production and release of T3 and T4]. It is also expected that the students know the main stimulus for the release of thyroid hormones (cold), as well as the effects of these hormones on the maintenance of body temperature (increase of cellular metabolism)
Female reproductive	Relate the hormones released during the menstrual cycle with the physiological events that occur during this period,
system	<i>beginning after the last menstruation.</i> In this station, students should relate the hormones released during the menstrual cycle with the physiological events that occur during this period, starting after the last menstruation. At this point, follicle-stimulating hormone (FSH) (pituitary hormone) levels are elevated and lead to maturation of ovarian follicles until the development of the dominant follicle, which in turn secretes high amounts of estrogen (ovarian hormone). The high and sustained concentration of estrogen activates the positive feedback loop, leading to the peak of luteinizing hormone (LH) (pituitary hormone), favoring ovulation. Then the remaining cells present in the ovary are transformed into the corpus luteum, a structure responsible for producing high levels of progesterone (ovarian hormone), a hormone responsible for maintaining the endometrium.
Male reproductive system	<i>Relate the hormones with the events that occur in the testicles. How is the release of male gonadal hormones controlled?</i> In this question, students are expected to identify the main hormone produced by the male gonad (testosterone) and show what the regulating axis of this hormone is [gonadotropin-releasing hormone (GnRH), released by the hypothalamus, stimulates the production and release of LH and FSH by the adenohypophysis, which will act on the gonads, stimulating the production and release of testosterone]. Students are also expected to know that Leydig cells are responsible for hormone production (testosterone), whereas Sertoli cells are directly involved in maintaining spermatogenesis.

ment on the posttest compared with the pretest, whereas the remaining three suffered virtually no variation.

On top of good performance, the Endocrine Circuit activity was also well received by the students. All students affirmed the activity helped them learn about the subject; they also liked it, considering it to be preferable to a traditional theoretical class. In a scientific context, it is known that data reported by students are prone to subjectivity, but the general view of the present study is positive, due not only to the feedback from the participant students, but also to the explicit interactive nature of the performed activity itself.

The students' enjoyment throughout the activity is likely another mechanism by which the positive results were achieved. There is evidence that fun and enjoyable approaches can improve learning in adult students (6). Although we did not measure any objective metrics of "fun" (a very subjective concept), it is possible to estimate their enjoyment through the question, "Did you like the activity?", which unanimously had

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Table 2. Questionnaire 1

Question	Response Options
<i>1</i> . Regarding the action of hormones in the organism.	<i>a)</i> Hormones are molecules secreted into the bloodstream and act solely on tissues distant from where they are released.
indicate the correct alternative:	 b) They need to be in very high concentrations to exert their effects. c) Cholesterol is the precursor molecule of steroid hormones produced in the suprarenal cortex; however, it is not the precursor of steroid hormones produced by the gonads.
2. Regarding the hypothalamus- adenohypophysis axis is it	d) To exert their effects on the target cell, hormones need the presence of a membrane or intracellular receptor.a) Adenohypophysis is not capable of producing hormones, because it is not made of cells with an endocrine character
correct to say that:	 b) The hormones involved in the hypothalamus-adenohypophysis axis are CRH (corticotropin-release hormone), ACTH (adrenocorticotropic hormone), and cortisol. c) One of the mechanisms that controls the hormones of the hypothalamus-adenohypophysis axis is the positive feedback loop; however, negative feedback loops do not control the release of those hormones.
3. Regarding the adrenal gland, which of the following is true?	 d) None of the above. a) The secretion of hormones from the cortex and the medulla occurs through the same stimuli. b) The secretion of hormones from the cortex occurs through hypothalamus-adenohypophysis axis signaling. c) The secretion of cortisol, aldosterone, and ADH (antidiuretic hormone) occur through hypothalamus-adenohypophysis axis signaling.
	<i>d</i>) The medulla of the adrenal gland is responsible for the production and release of epinephrine and is stimulated by the parasympathetic nervous system.
 Regarding the production of thyroid hormones (T3 and T4), choose the correct 	a) The signaling pathway that leads to the production of tyroid hormones consists in the inhibition of the enzymes AC (adenylate cyclase) and PLC (phospholipase C), through the ligation of TSH (thyrotropin release hormone) to its receptor.
alternative:	 b) The thyroid hormones act on their target cells through the ligation to their membrane receptors, unleashing its intracellular signaling pathway. c) Cell may crimulate the release of thuroid hormones, which lead to an increase of the organism's thermocanacian.
	 a) The main action of the thyroid hormones is related to increase of fat deposition in the organism.
5. Regarding the endocrine pancreas, indicate the correct alternative:	 a) The pancreatic β-cell is responsible for the production of insulin hormone, which secretion is controlled by neural, hormonal, and nutritional stimuli, with glucose being the main substrate responsible for that regulation. b) The main effect of insulin in the skeletal muscle is the inhibition of the hepatic production of glucose (gluconeogenesis).
	 c) The pancreatic δ-cell is responsible for the production of glucagon, a hormone responsible for the regulation of glycemia after feeding. d) The precursor molecule of pancreatic hormones is cholesterol; therefore, all of these hormones possess intracellular
 Regarding the role of the liver during different nutritional states (fasting and 	receptors.a) During fasting, the insulin hormone acts on the liver, stimulating hepatic production of glucose (gluconeogenesis).b) During fasting, the glucagon hormone acts on the liver, stimulating hepatic production of glucose (gluconeogenesis).
fed), choose the correct alternative:	 c) During the fed state, the insulin hormone acts in the liver, stimulating the translocation of type 4 glucose transporters (GLUT-4), favoring the uptake of glucose by this tissue. d) During the fed state, the glucose hormone acts in the liver, inhibiting hungar.
7. Regarding different nutritional states (fasting and fed) it is correct to say that	 a) During the fed state, the glucagon hormone acts in the river, inhibiting hunger. a) During fasting, GH (growth hormone) is released and, consequentially, muscle mass is increased. b) After a meal rich in carbohydrates and fat, there is an increase in the release of GH and, consequentially, an increase of muscular mass.
in the skeletal muscle:	 c) During prolonged fasting, there occurs a release of the cortisol hormone, leading to an increase of muscular proteolysis, to generate substrate for production of hepatic glucose (gluconeogenesis). d) During prolonged fasting, there is a reduction in the cortisol hormone, leading to an increase in muscular
8. Choose the correct alternative regarding what happens in the adipose tissue during the different nutritional states (fasting and fed):	 proteolysis, to generate substrate for hepatic gluconeogenesis. a) During prolonged fasting, the hormone leptin is released, and it is responsible for stimulating hunger. b) During prolonged fasting, the release of the hormone epinephrine occurs, leading to an increase of lipolysis, aiming to generate substrate for hepatic production of glucose (gluconeogenesis). c) During prolonged fasting, the hormone epinephrine is released, leading to a reduction of lipolysis, to generate substrate for hepatic production of glucose (gluconeogenesis).
 Regarding the female reproductive system indicate 	d) The hormone glucagon, released after feeding, will stimulate lipogenesis.a) During the menstrual cycle, the increase in luteinizing hormone (LH) concentration leads to the maintenance of the ovarian follicle.
the correct alternative:	 b) During the menstrual cycle, the increase in follicle stimulating hormone (FSH) concentration leads to ovulation. c) After its formation, the corpus luteum will be responsible for the production of great quantities of the hormone progesterone, which will act to maintain the endometrium. c) After its formation the corpus luteum will be responsible for the production of great quantities of the hormone progesterone, which will act to maintain the endometrium.
10. Regarding the male	a) After its formation, the corpus futerint will be responsible for the production of great quantities of estrogen, which will act in the maintenance of the endometrium.a) Spermatogenesis is controlled solely by the hypothalamus-adenohypophysis axis, with the gonads endocrine cells
reproductive system, indicate the correct alternative:	having no action over this phenomenon. b) Testosterone is produced by the Leydig cells and may be converted into dihydrotestosterone (DHT), but not converted into estrogen
	<i>c</i>) Sertoli cells are considered to be the support cells, having close contact with all of the other spermatic cells, while the main function of the Leydig cells is to produce hormones.
	d) Testosterone acts on the organs of the reproductive system, presenting important actions related to the secondary male characteristics. However, it does not possess any important structural or metabolic action.

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Question	Response Options
<i>1</i> . Did the activity help with your understanding	a) It did not help
about Physiology of the Endocrine System?	b) It partially helped
	d) It helped a lot
2. Did you like participating in the activity?	a) I did not like it
	b) I partially liked it
	c) I liked it
	d) I liked it a lot
3. Do you consider the activity more effective	a) No
than a theoretical, expositive class?	b) Indifferent
-	c) Yes
4. On a scale from 0 to 10, how do you evaluate the developed activity?	0–10

positive responses. As such, the fact that students liked the activity may have been a motivator that promoted learning success.

In conclusion, we have developed an engaging teaching method that improves undergraduate students' knowledge regarding Human Endocrine Physiology. This method could be applied in classrooms worldwide to improve the teaching of physiology in biology and health courses. Besides, with a few tweaks, it is possible to modify this activity to encompass subjects beyond physiology. This can be achieved by keeping the overall methodology (the multiple stations, the questions, the multiple "pieces" of the "puzzle" that leads to the answer, etc.) but changing the subject to whatever one may desire. Even though it would require some effort, it could be an interesting way for professors to diversify their lectures.

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DISCLOSURES

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

Table 4. Performance on tests before and after EndocrineCircuit application

Question No.	Pretest	Posttest	P Value
1	61 (98)	60 (97)	0.56
2	28 (45)	33 (53)	0.37
3	18 (29)	40 (65)*	< 0.001
4	44 (71)	62 (100)*	< 0.001
5	55 (89)	55 (89)	>1.00
6	37 (60)	51 (82)*	0.005
7	41 (66)	56 (90)*	0.001
8	40 (65)	58 (94)*	< 0.001
9	30 (48)	56 (90)*	< 0.001
10	43 (69)	57 (92)*	0.001

Values are no. of answers (with the percentage in parentheses) to each question that were correct on the pretest vs. posttest (n = 62 students). *Significant differences (Student's *t* test, $P \le 0.05$).



Fig. 2. Performance of the students on the 10 questions of the questionnaire. Data show the percentage of students' correct answers on the pretest and the posttest. Values are means and standard deviation (SD) (Student's *t* test; P = 0.02) (n = 62 students).

AUTHOR CONTRIBUTIONS

L.Z., G.M.S., and H.C.d.L.B.-S. conceived and designed research; L.Z., G.M.S., L.R.d.O.R., K.R.S., G.A.B., E.M.-J., E.M.C., and H.C.d.L.B.-S. performed experiments; L.Z. and G.M.S. analyzed data; L.Z., G.M.S., E.M.-J., E.M.C., and H.C.d.L.B.-S. interpreted results of experiments; L.Z., G.M.S., and K.R.S. prepared figures; L.Z., L.R.d.O.R., G.A.B., and H.C.d.L.B.-S. drafted manuscript; L.Z., G.M.S., L.R.d.O.R., K.R.S., G.A.B., E.M.-J., E.M.C., and H.C.d.L.B.-S. edited and revised manuscript; L.Z., G.M.S., L.R.d.O.R., K.R.S., approved final version of manuscript.

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Fig. 3. Students' perception of the impact of the activity on improving their knowledge of endocrine physiology (*A*), acceptance of the activity (*B*), their opinion about the efficiency of the Endocrine Circuit compared with theoretical classes (*C*), and their scores assigned for the Endocrine Circuit activity (*D*) (n = 62 students).