Forcing a change: a learn-by-doing workshop on circadian rhythms to understand the complexities of human physiology

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Abstract

Physiology is an integrative science that requires an understanding of the organism as a whole to acquire a deep comprehension of its functions and avoid misconceptions that may impair further learning. Thus it is necessary to develop resources that promote the integrative vision that Physiology requires. Chronobiology is a challenging discipline and one of the least addressed concepts in Physiology curricula. The activity here presented proposes a workshop with a theoretical-practical perspective in the context of the Neuroscience Conferences held annually at our university. All conference presentations are neuroscience-related topics, in combination with practical activities, some of them analyzing variables of the students themselves. We chose to assess this informal teaching scenario to involve the students with a scientific perspective while learning and hoping to increase their appreciation for different topics related to neuroscience. Specifically for this activity on chronobiology, the evaluation was carried out via a survey study including quantitative and qualitative questions and semistructured personal interviews. In general, the results reveal a very positive opinion from students regarding aspects such as the teaching methodology, the organization before and during the activity or the added value of the experience for their future professional performance. Some of the students stated they were more aware of the importance of their circadian system and even changed some of their personal daily routines after the activity. Such positive feedback encourages us to continue working in this theoretical-practical format in the future, as it contributes to improving students’ perception of their own learning.

chronobiology; integration; learn-by-doing; physiology

INTRODUCTION

Human Physiology is widely perceived as a challenging subject in medical degrees, often characterized by early drops and moderate failure rates (1–3). It has been observed that students struggle to succeed and consider Physiology to be a difficult discipline, a fact that is mainly attributed to three different domains: 1) the nature of the subject, 2) the ways instructors teach it, and 3) students’ preconceived notions about the course (4).

Difficulty in understanding Human Physiology is influenced by the need to adopt a dynamic systems perspective and use cognitive abilities for causal reasoning and integration across levels (e.g., cellular and biochemical) (5). This is often challenging for new students, who may tend to compartmentalize isolated facts without realizing how the levels and systems of the human body are interrelated and interdependent. The ability to make predictions about how external and internal changes will affect the state of a system requires assistance to be mastered (6). On their own, students associate studying with memorizing concepts, while Physiology is a science that calls for a causal approach. However, as it requires a strong background on chemistry, biology, and physics, understanding physiological mechanisms is never a purely mnemonic process (4, 7, 8). Moreover, many students who have previously completed science courses will have acquired knowledge of scientific concepts that they may not use in a flexible manner to interpret physiological concepts that require a more mechanistic or causal point of view. One interesting approach to solving this challenge is teaching basic sciences while focusing on their application. In this context, the teaching of Physiology would benefit from activities designed to develop skills from the upper levels of Bloom’s taxonomy, which focus on higher-order thinking skills (analyze, evaluate, and create) (9).

While faculty and students tend to agree that Physiology is inherently challenging, their perceptions may not be the same. Students commonly establish their first contact with Physiology when coming from different backgrounds and lacking the basic knowledge and skills required (10). As such, most teachers feel students may not be ready and recognize their misconceptions about physiological phenomena (9, 11). This is particularly critical because the way physiological knowledge is integrated may strongly influence subsequent learning. Thus, in recent years, new methodologies have been introduced to change the students’ approach from “why” to a...
more mechanistic “how” perspective (12). Adopting a more participatory, integrative, and multidisciplinary teaching approach makes it possible to better target Bloom’s major axes (13).

Based on previous models proposing extra classes that promote student-teacher interaction (9), we have conducted an exploratory experience in the first year of science degrees (primarily in Medicine) to push the teaching of Physiology beyond the limits of the traditional classroom-laboratory context. We chose a fairly complex concept such as circadian rhythms to test whether adopting a participatory and integrative learn-by-doing approach has any impact on students’ understanding and perception. The experience described here consisted of a workshop at the Neuroscience Conferences, organized annually since 2016 at Universidad Europea (Madrid, Spain). The topic of the workshop was chosen based on two aspects: first, chronobiology is a concept with a relatively marginal presence in traditional Physiology curricula, making it a secondary subject for medical students (14, 15); second, when students have to comprehend it, they appear to find it complicated. Thus we believe that by presenting chronobiology from a theoretical-practical point of view and in the context of a scientific Conference (with different format than that of a traditional class), we could help involve students with a scientific perspective while putting into practice their knowledge.

All these factors encouraged us to submit this experience to a call organized annually by the Spanish Society of Physiological Sciences, who awarded this activity the 1 Prize of Excellence in Physiology Teaching.

## MATERIALS AND METHODS

The activity presented here is centered on a complicated physiological concept, specifically chronobiology, approached from a theoretical-practical perspective. To reinforce students’ motivation, it took place as part of the Neuroscience Conferences organized annually at Universidad Europea, in which students could attend lectures and participate in 2 out of 12 different workshops held throughout the day that discuss neuroscience from diverse points of view. These included workshops about chronobiology, malnutrition and brain development, pharmacogenetics of antipsychotics, or the psychobiology of addiction, among others. This paper focuses on the chronobiology workshop, given the relevance of the topic to Physiology and the ease of access to students’ data by the authors.

### Participants

All the workshops were offered to students in the first year of Medicine Degree (n = 526) and second year of Biotechnology Degree (n = 20). The Neuroscience Conferences were organized at the beginning of second semester, so students had a certain background in neurophysiology by the time they took place. The workshop on chronobiology was entitled “How to set our biological clock? Implications of the nervous system in the circadian rhythms.” In the present article, we consider data from the three annual editions of the Neuroscience Conferences. Twenty-four students attended the workshop at each of the second and third editions, distributed across the morning and afternoon sessions (12 students each), and 12 students attended the first edition (60 students in total). All these students chose to participate in this workshop voluntarily, from among the other 11 offered, based on their personal interests and preferences.

### Description of the Activity

The dynamics of the workshop consisted of a presentation of the basic concepts of chronobiology (in PowerPoint format) followed by practical activities that facilitated comprehension and assimilation of the concepts presented previously. This design seeks to present theoretical concepts in a practical work scenario.

The teaching objectives were as follows:

1. To acquire knowledge on basic chronobiological concepts.
2. To understand the role of the central nervous system in the response to rhythmic environmental stimulus.
3. To expose students to the practical application of chronobiology.

Briefly, the workshop began by defining chronobiology to bring students’ attention to the concept of circadian rhythms. After presenting different classical experiments, the neural pathway for light transmission and the role of the hypothalamic suprachiasmatic nucleus and the pineal gland were emphasized. Students were subsequently invited to exercise this knowledge by means of sagittal anatomical models of the head and neck and two schemes to fill in with the name of the indicated elements. With this practical activity, we intended for students to internalize the concepts previously discussed. Together with other documents, these schemes were included in a booklet provided to the students at the beginning of the workshop, which contained the materials needed to carry out all the activities.

The presentation continued explaining outputs of the internal clocks, in the form of observable rhythms, such as motor activity, temperature, sleep-wake cycle, glycemia, blood pressure, sensorimotor coordination, reaction time, etc. We defined circadian rhythms that, although correct, may be slightly advanced (diurnal chronotype) or delayed (nocturnal chronotype) with respect to the biological rhythm determined by the environment. We then asked students to check their chronotypes by answering the “Morningness-Eveningness Questionnaire” (16), also included in the student booklet.

Finally, students were asked to evaluate the circadian system of some patients with alterations to their sleep-wake cycles (night worker, shift worker, etc.) provided in the booklet, as an attempt to integrate the concepts they acquired during the class and to apply them to real clinical cases. The instructors explained to the students how to analyze data and directed the discussion of this analysis and interpretation, finally providing a conclusion on patients’ situation.

Besides analyzing the reports from patients, some randomly selected students (3 in each session, 15 students in total) had received a device (Kronowise 6, Kronohealth) to record their own circadian data during at least 7 days. Briefly, the device, placed around the wrist, continuously records three variables (peripheral temperature, motor activity and position) and combines to obtain the parameter
temperature-activity-position (TAP), which gives an indirect idea of the sleep quality of the experimental subject (17). Anonymized data were collected in a report along with other details, such as the chronobiological age of the subjects and personal recommendations to improve the quality of their circadian system. All anonymized data and analyses were discussed in group.

The instructor ended the workshop by describing a list of different factors that affect our circadian rhythm (aging, jet lag, light pollution, etc.) and associated pathologies. Among the adverse effects of chronodisruption (the term that describes alterations to biological rhythms) are as follows: impaired hormone production (menstrual cycle disruption, etc.), mental disorders (stress, depression, etc.), increased risk for cardiovascular and gastrointestinal disorders, cancer, reproductive effects, etc. The last minutes of the workshop were dedicated to going through the recommendations of various sleep institutes to maintain a healthy circadian system.

Throughout all activity, students were invited to ask questions at any point during the presentation and to speculate, hypothesize, and debate around the challenges that the instructors set out.

**Measurements, Data Collection, and Evaluation of the Activity**

Analysis of students’ experience of and perspective on the activity were created using quantitative and qualitative methods.

**Quantitative.**

Immediately after the workshop, students were asked to fill out an anonymous survey, that consisted of 11 Likert-scale questions (1: strongly disagree, 5: strongly agree) adapted from Hounsell (18):

1) The workshop was well organized (information, compliance with dates/times, material delivery, etc.).
2) The number of students in the group was appropriate for the workshop.
3) The contents of the workshop have added value to my academic training.
4) There was an appropriate combination of theory and practice.
5) The duration of the workshop was appropriate for its objectives and contents.
6) The methodology of the workshop has facilitated my learning.
7) The documentation and materials delivered are understandable and adequate.
8) The classroom and technical facilities were adequate for the workshop.
9) The workshop has enabled the acquisition of new skills/abilities that may be useful for my future professional development.
10) During the development of the workshop, I could apply the technical content acquired to the practical activities.
11) General perception of the workshop.

For data analysis, we calculated the percentage of students who selected each level of Likert scale (n = 45 students), and the average ± SD of their assessment.

**Qualitative.**

Students whose circadian variables were monitored by the device were asked to complete a second anonymous survey consisting of open questions, which aims to explore whether wearing the device made them more aware of the existence of a circadian rhythm and the importance of taking care of it. These questions were written in GoogleDocs and sent to the students by e-mail. The questionnaire started with an explanation of the aim of the study and stating that, by answering it, they consent to the use of their responses for research purposes. The survey contained the following four open questions:

1) Do you feel that wearing the device for a few days prior to the workshop has facilitated your readiness to understand the theoretical concepts?
2) Do you feel that wearing the bracelet device and having the resulting report about your circadian rhythm has made you more aware of the system and its care?
3) Have you changed any of your habits in relation to your circadian system after using the device and receiving your report?
4) Do you think there is any negative aspect associated with wearing the device?

The written responses (n = 6 students) were analyzed using thematic analysis (19). Additional to these questionnaires, the same students who wore the device were invited to participate in a personal semistructured interview. A total of n = 5 students agreed to take part on it, and they were planned and conducted via Microsoft Teams. After the transcriptions were completed, a thematic analysis was conducted (19). Quotes corresponding to the questionnaire answers are reported as text in the RESULTS, while quotes from the semistructured interviews are reported in Table 2.

Before any data collection, the students were informed about the objective of the study and the use of their responses. The present study meets regulations by Spanish Personal Data Protection laws as laid out in Organic Law 15/1999.

**RESULTS**

**Quantitative Analysis**

For a better analysis of the students’ responses, we classified the 11 questions of the survey into 4 different topics: organization and planning (questions 1, 2, 5, and 8), theoretical-practical content and added value of the workshop (questions 3, 4, 9, and 10), teaching methodology (questions 6 and 7), and general satisfaction with the workshop (question 11).

A general overview of the topics, questions and students’ assessment (average ± SD) for quantitative analysis can be found in Table 1.

**Organization and planning.**

The analysis of the answers related to the organization and planning of the workshop (questions 1, 2, 5, and 8) reveals a very high percentage (around 83–96%) of students showing the highest degree of agreement (Fig. 1). In fact, no student negatively assessed (disagree or strongly disagree) the workshop in relation to the general organization (question 1) or the adequacy of the number of participants in the workshop.
Only a very small percentage of the students (<5%) manifested a neutral opinion on aspects related to the organization and duration of the workshop or the spaces and facilities provided for its development (questions 1, 5, and 8).

Theoretical-practical content and added value of the workshop.
The results show a very high percentage (>90%) of students that assess the contents of the workshop positively (agree and strongly agree) and consider that it adds value to their professional development (Fig. 2). Only a small percentage of students (2% to 7%) expressed a neutral opinion on aspects such as the added value of the workshop, the adequate balance between theoretical and practical content, or its contribution to their professional development. A small percentage of students (2%) considered the combination of practice and theory in the workshop not to be adequate (question 4).

### Table 1. General overview of the topics, questions, and students’ assessment for quantitative analysis

| Question                              | Question Statement                                                                 | Values    |
|---------------------------------------|-----------------------------------------------------------------------------------|-----------|
| Organization and planning             |                                                                                   |           |
| Question 1                            | The workshop was well organized (information, compliance with dates/times, material delivery, etc.). | 4.78 ± 0.51 |
| Question 2                            | The number of students in the group was appropriate for the workshop.              | 4.96 ± 0.21 |
| Question 5                            | The duration of the workshop was appropriate for its objectives and contents.      | 4.84 ± 0.42 |
| Question 8                            | The classroom and technical facilities were adequate for the workshop.             | 4.84 ± 0.42 |
| Theoretical-practical content and added value of the workshop |                                                                                   |           |
| Question 3                            | The contents of the workshop have added value to my academic training.             | 4.78 ± 0.55 |
| Question 4                            | There was an appropriate combination of theory and practice.                       | 4.64 ± 0.74 |
| Question 9                            | The workshop has enabled the acquisition of new skills/abilities that may be useful for my future professional development. | 4.76 ± 0.52 |
| Question 10                           | During the development of the workshop, I could apply the technical content acquired to the practical activities. | 4.76 ± 0.52 |
| Teaching methodology                  |                                                                                   |           |
| Question 6                            | The methodology of the workshop has facilitated my learning.                       | 4.82 ± 0.44 |
| Question 7                            | The documentation and materials delivered are understandable and adequate.         | 4.87 ± 0.4 |
| General satisfaction with the workshop|                                                                                   |           |
| Question 11                           | General perception of the workshop.                                               | 4.87 ± 0.34 |

Values are average assessment of the question ± SD, considering Likert scale; n = 45.

(questions 2). Only a very small percentage of the students (<5%) manifested a neutral opinion on aspects related to the organization and duration of the workshop or the spaces and facilities provided for its development (questions 1, 5, and 8).

**Figure 1.** Assessment of the organization and planning of the workshop (in parenthesis, the average assessment of each question ± SD, considering Likert scale).
Teaching methodology.
The results show that almost 100% of the students felt that this teaching methodology had facilitated learning positively (85% strongly agree and 13% agree) (Fig. 3, question 6). Likewise, 98% of students positively assessed the material provided to the students (Fig. 3, question 7). Only 2% of students manifested a certain degree of disagreement with both statements.

General satisfaction with the workshop.
All the students valued this item very positively (87% strongly agree, 13% agree), while no neutral or negative answers (disagree or strongly disagree) were recorded (Fig. 4).

Qualitative Analysis
From the open questions in the questionnaire, all students agreed that wearing the device and receiving a personalized report helped them have a clearer understanding of the theoretical concepts around circadian rhythms. All students felt that having taken part in the activity has increased their awareness about circadian rhythms and their care. One of the students described the experience as:

“… Completely. I felt I was so fortunate to have this experience and having seen my own results…; as a student at times we prioritize studying over health, for instance in the sense of getting proper rest. Even though we know about it, and study it, this activity has helped me to become really aware and visualize how it really works and how important it is for our cells” (student 1).

Three students reported minor discomfort associated with wearing the device, but all agreed that it was still worth the experience.

One of the students stated:

“… In my opinion, there is nothing negative about the experience. I think it is something everyone
should know and go through, learning about one own´s rest and how to ensure you get proper sleep as I think most of us wake up feeling tired when, in reality, this could be easily solved…” (student 5).

Another student even changed his/her daily habits after attending the workshop, explained that he/she stopped napping during the day and reported a better night sleep after including some of the recommendations provided in his/her routines.

On the other hand, the interview analysis was organized around deductive and inductive themes and provided the following results in Table 2.

## DISCUSSION

The activity discussed here presents a concept, which is usually perceived as difficult by students, from an integrative theoretical-practical perspective in a workshop format within a scientific conference. We believe that this approach extends beyond the more traditional lecture-laboratory contexts, allowing for better motivation of students and reinforcing the learning process.

The topic chosen was chronobiology because, beyond its difficulty, it is poorly represented in Health Sciences curricula, and specifically in Physiology programs. Thus we believe that it is extremely important that its teaching is addressed in order to achieve the most lasting and integrative learning possible. We believe that the design of our workshop, with a theoretical-practical and a learn-by-doing approach, is optimal for this purpose, since it pursues a constructive learning of chronobiology (14, 20). Ultimately, this constructive perspective encourages engagement and motivation, leading to an improved learning experience, long-term knowledge, and significant skills development (21, 22).

Based on students’ perceptions, the aspect best valued was the teaching methodology applied. When designing the activity, we were aware that, due to the difficulty inherent in teaching and understanding Physiology (1–3), we had to offer opportunities for students to actively participate in the class and to integrate the functioning of our organism as a whole in a more holistic manner. To this end, we believe that the added value of our activity lays in the combined explanation of theoretical concepts and their application in a practical manner, with continuous feedback and significant student-instructor interaction, creating an environment of confidence that promotes long-term understanding. This is also supported in the students verbatim, as reflected in Table 2.

The creation of such a supportive and active learning environment has been previously demonstrated to promote the learning of Physiology, leading to increased performance and improvement of students’ overall learning experience (22–25).

An important part of this environment is the immediate feedback, as this helps students to observe the strengths and weaknesses of their understanding and offers the opportunity to improve any unsatisfactory aspects. As Ernst and Colthorpe (26) stated, students who are interested and engaged in learning activities, and who are being encouraged to think and receive constant feedback, will become confident in their learning abilities and achieve improved learning outcomes. In our activity, feedback was provided continuously, as students were encouraged to ask and discuss any aspect they considered important, as a way to increase their motivation, satisfy their curiosity, and offer them the opportunity to integrate and apply chronobiology to daily situations.

To improve the positive impact of all these aspects even more, the role of an experienced, enthusiastic, and skilled educator, who designs the activity and provides quality instructional material and experiences, is vital (20, 22, 27, 28).

### Table 2. Themes and associated verbatim from semistructured interviews

| Themes                        | Verbatim                                                                 |
|-------------------------------|--------------------------------------------------------------------------|
| Impact of previous workshop organization on learning | “If the previous scenario is positive and you see a positive flow of information… I believe that it predisposes you to have a better attitude towards the activity” (student 7) |
| Methodology                   | “If you engage with the topic in a practical way you will be able to retain theoretical concepts in a more active manner” (student 7)“Merging theory with practice makes the workshop more interesting” (student 4)“To be in small groups was a differentiating factor, it favored discussion” (student 2) |
| Feedback                      | “The small groups and the possibility of asking questions and being able to receive immediate feedback was an important differentiating factor” (student 5) |
| Professor’s role              | “You feel more eager as you see the professor more eager to teach you in a different way” (student 3) |
| Ability to choose the topic of workshop | “Yes, most definitely (motivating) as there are workshops to choose from” (student 2) |
| Access to students’ own data  | “I think wearing the device greatly boosts motivation for the workshop” (student 5)“When you are seeing something reflected in yourself, you will obviously remember it” (student 3) |
| Clinical application          | “If I had the chance, I would recommend it to my patients” (student 7)“When you experience it yourself, you are more eager to apply it to other people” (student 4) |
| Self benefits                 | “I tried to implement what I learned in the workshop in my daily routines” (student 3) |

Five students were interviewed.
The role of the instructor, then, is to create environments in which learning is likely to occur (29). In this sense, besides other aspects, such as active learning and a supportive environment, student-staff interaction is another element that promotes student engagement (30). Endo and Harpel (31) observed that staff-student interactions are not only useful for the discussion of content but may also help students to develop problem-solving abilities. Acquiring these abilities has a positive impact on their approach to studying and the application of the knowledge acquired to life in general. Importantly, student-centered learning approaches are more efficient if the teacher has the primary role of providing high quality instructional material and immediate feedback (32). In our activity, we paid special attention to the instructor-student relationship, and we believe that the dynamics of the workshop, with fewer students than a lecture hall, favored and encouraged the continuous and direct interaction between them. All these positive aspects are maximized when students are allowed to voluntarily participate in the activities (22), as occurred in this workshop and was appreciated in students’ comments (Table 2). Besides all this, the instructor designed the material (which, as the results show, was considered adequate and at their level), not only covering the theoretical basis of chronobiology, but also touched on the real application of that material. As previously stated, the provision of tasks, materials, and activities that are relevant and useful to students highly motivates them in the learning process (33).

However, the role of the instructor is not only important in the design and implementation of the activity but also in the upstream organization and communication with the students that will take part of it. These aspects also help to create an environment of confidence, as it implies a deep involvement of the instructor in the activity from the beginning. In this sense, the organization and planning of our workshop were two of the best-valued aspects: almost all students agree that the general organization (information provided, timetable and dates, etc.), the spaces and facilities, and the duration of the activity are appropriate for the objectives and contents of the workshop. As is shown in Table 2, students consider that an adequate organization predisposes them to a better learning attitude.

One aspect that is assessed very positively is the theoretical-practical perspective and the added value of the activity (acquisition of new abilities and skills that could be useful in their future work). The combination of a scientific and practical orientation, successfully implemented, promotes independence and experimentation by the students and improves learning and future professional performance (34). Goodman and coworkers (35) understand that meaningful learning occurs when students are able to solve appropriate problems with the information they have acquired. Similarly, Yang and coworkers (36) state that the combination of theory and practice improves academic achievement and the development of important professional skills in Health Sciences professionals. In recent years, Piedmont and Robra (37) carried out a study to evaluate the expectations of Human Medicine students for the content of their degree, finding that this profile of students has a high interest in carrying out practical work that prepares them for their profession. These studies reinforce our own results, as the students very positively assess the theoretical-practical perspective of the workshop and understand that it promotes the acquisition of abilities that could be useful in their future profession.

Finally, those students who wore the recording device stated that they are more aware of the existence of a circadian system and that they have even changed their daily routines to keep it in good health, as it is shown in Table 2. This exercise requires commitment from the participants to taking care of the material and being honest and precise when performing the measurements. In a previous study carried out by Rol de Lama and coworkers (15), the results indicate that students who measure their own physiological parameters manifest an increased interest and motivation in chronobiology. In fact, when analyzing data recorded by the device, many students were amazed when they realized how much they moved while sleeping or how badly they slept. They even stated that they would try to change their routines afterwards, which will likely drive them to stop considering biological rhythms to be a secondary issue. In addition, it can be inferred from their responses to the interviews (Table 2) that they would not forget that the chronobiological features of a patient should be taken into account when considering the most suitable time to diagnose or treat a medical condition.

In conclusion, this workshop introduces students to a rarely valued aspect of Physiology, chronobiology, adopting a participatory and practical learn-by-doing approach. This experience was highly interesting and motivating for students, as they were able to apply chronobiological concepts to clinical cases and to become conscious of circadian physiology themselves. Such positive outcomes encourage us to continue designing activities framed using this theoretical-practical perspective to contribute to and facilitate student’s learning process.

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### DISCLOSURES

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

### AUTHOR CONTRIBUTIONS

C.A. conceived and designed research; C.A. and P.S. performed experiments; C.A., P.S., A.S., and M.L. analyzed data; C.A., P.S., and M.L. interpreted results of experiments; C.A. and P.S. prepared figures; C.A. and B.G. drafted manuscript; C.A., P.S., A.S., M.L., and B.G. edited and revised manuscript; C.A., P.S., A.S., M.L., and B.G. approved final version of manuscript.

### REFERENCES

1. Harris DE, Hannum L, Gupta S. Contributing factors to student success in Anatomy & Physiology: lower outside workload & better
preparation. Am Biol Teach 66: 168–175, 2004. doi:10.2307/4441650.
2. Hopper MK. Student enrollment in a supplement course for Anatomy and Physiology results in improved retention and success. J Coll Sci Teach 40: 70, 2011.
3. Sturges D, Maurer TW, Allen D, Gatch DB, Shankar P. Academic performance in human anatomy and physiology classes: a 2 yr study of academic motivation and grade expectations. Adv Physiol Educ 40: 26–31, 2016. doi:10.1152/advan.00091.2015.
4. Michael J. What makes physiology hard for students to learn? Results of a faculty survey. Adv Physiol Educ 31: 34–40, 2007. doi:10.1152/advan.00057.2006.
5. Sturges D, Mauner T. Allied health students’ perceptions of class difficulty: the case of undergraduate Human Anatomy and Physiology classes. Internet J Allied Health Sci Pract 11: 4, 2013.
6. Zohar A. Reasoning about interactions between variables. J Res Sci Teach 32: 1039–1063, 1995. doi:10.1002/tea.3660321005.
7. Higgins-Opitz SB, Tufts M. Performance of first-year health sciences students in a large, diverse, multidisciplinary, first-semester, physiology service module. Adv Physiol Educ 38: 161–169, 2014. doi:10.1152/advan.00007.2013.
8. Reinke NB, Llewelyn V, Firth N. Developing discipline-specific study skills for pharmacy students learning anatomy and physiology. Int J Innov Sci Math Educ 31, 2016. doi:10.1152/advan.00091.2015.
9. Michael JA. Studies’ misconceptions about perceived physiological responses. Adv Physiol Educ 274: S90, 1998. doi:10.1152/advances.1998.274.6.S90.
10. Rovick AA, Michael JA, Modell HL, Bruce DS, Horwitz B, Adamson T, Richardson DR, Silverthorn DU, Whitescarver SA. How accurate are our assumptions about our students’ background knowledge? Adv Physiol Educ 276: S93, 1999. doi:10.1152/advances.1999.276.6.S93.
11. Michael JA, Wenderoth MP, Modell HL, Clift W, Horwitz B, McHale P, Richardson D, Silverthorn D, Williams S, Whitescarver S. Undergraduates’ understanding of cardiovascular phenomena. Adv Physiol Educ 26: 72–84, 2002. doi:10.1152/advan.2000.00002.2002.
12. Southland SA, Abrams E, Cummins CL, Anzelmo J. Understanding students’ explanations of biological phenomena: conceptual frameworks or p-prims? Sci Ed 85: 328–348, 2001. doi:10.1002/sce.1013.
13. Crowe A, Dirks C, Wenderoth MP. Biology in bloom: implementing Bloom’s Taxonomy to enhance student learning in biology. CBE Life Sci Educ 7: 368–381, 2008. doi:10.1187/cbe.08-05-0024.
14. Bravo R, Cubero J, Rodríguez A, Barriga C. La Cronobiología en la Educación Superior: un recurso para la innovación docente en la Fisiología. Rev Educ Cienc Salud 12: 119–124, 2015.
15. Rol de Lama MM, Lozano JP, Ortiz V, Sánchez-Vázquez FJ, Madrid JA. How to engage medical students in chronobiology: an example on autorhythmometry. Adv Physiol Educ 29: 160–164, 2005. doi:10.1152/advan.2000.00005.2004.
16. Smith CS, Reilly C, Midkiff K. Evaluation of three circadian rhythm questionnaires with suggestions for an improved measure of morniness. J Appl Psychol 74: 728–738, 1989. doi:10.1037/0021-9010.74.5.728.
17. Ortiz-Tudela E, Martínez-Nicolás A, Campos M, Rol MÁ, Madrid JA. A new integrated variable based on thermometry, actimetry and body position (TAP) to evaluate circadian system status in humans. PLoS Comput Biol 6: e1000996, 2010. doi:10.1371/journal.pcbi.1000996.
18. Hounsell D. Evaluating courses and teaching. In: A handbook for Teaching and Learning in Higher Education: Enhancing Academic Practice, edited by Fry H, Ketteridge S, Marshall S. London: Routledge, chap 14, 2009.
19. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol 3: 77–101, 2006. doi:10.1191/1478088706qp063oa.
20. Kala S, Isaramalai SA, Pothong A. Electronic learning and constructivism: a model for nursing education. Nurse Educ Today 30: 61–66, 2010. doi:10.1016/j.nedt.2009.06.002.
21. Astin A. What Matters in College: Four Critical Years Revisited. San Francisco, CA: Jossey-Bass, 1993.
22. Carvalho H, West CA. Voluntary participation in an active learning exercise leads to a better understanding of physiology. Adv Physiol Educ 35: 53–58, 2011. doi:10.1152/advan.00011.2010.
23. Kiener M, Green P, Ahuna K, McCluskey J. The creation of the comfortability in learning scale. Transform Dialogue Teach Learn J 6: 1–9, 2013.
24. Reinke NB. Promoting student engagement and academic achievement in first-year anatomy and physiology courses. Adv Physiol Educ 43: 443–450, 2019. doi:10.1152/advan.00205.2018.
25. Rodenbaugh DW, Lujan HL, DiCarlo SE. Learning by doing: construction and manipulation of a skeletal muscle model during lecture. Adv Physiol Educ 36: 302–306, 2012. doi:10.1152/advan.00093.2012.
26. Ernst H, Colthorpe K. The efficacy of interactive lecturing for students with diverse science backgrounds. Adv Physiol Educ 31: 41–44, 2007. doi:10.1152/advan.200107.2006.
27. Hattie J. Teachers make a difference: what is the research evidence? Australian Council for Education Research Conference. Melbourne, Australia, 2003.
28. Lizzio A, Wilson K, Simons R. University students’ perceptions of the learning environment and academic outcomes: implications for theory and practice. High Educ 27: 27–52, 2002. doi:10.1007/1037507012009359.
29. Michael JA. Mental models and meaningful learning. J Vet Med Educ 31: 1–5, 2004. doi:10.3138/jvme.31.1.11.
30. Coates H. Engaging Students for Success—2008 Australasian Survey of Student Engagement. Victoria, Australia: Australian Council for Educational Research, 2009.
31. Endo JJ, Harpel R. The effect of student-faculty interaction on students educational outcomes. Res High Educ 46: 115–138, 1982. doi:10.1007/BF00973505.
32. Tsang A, Harris DM. Faculty and second-year medical student perceptions of active learning in an integrated curriculum. Adv Physiol Educ 40: 446–453, 2016. doi:10.1152/advan.00079.2016.
33. Pintrich PR. A motivational science perspective on the role of student motivation in learning and teaching contexts. J Educ Psychol 95: 667–686, 2003. doi:10.1037/0022-0663.95.4.667.
34. Friedrichs A, Schaub H. Academisation of the health professions—achievements and future prospects. GMS Z Med Ausbild 28: doc50, 2011.
35. Goodman BE, Barker MK, Cooke JE. Best practices in active and student-centered learning in physiology classes. Adv Physiol Educ 42: 417–423, 2018. doi:10.1152/advan.00064.2018.
36. Yang N, Xiao H, Cao Y, Li S, Yan H, Wang Y. Does narrative medicine education improve nursing students’ empathic abilities and academic achievement? A randomised controlled trial. J Int Med Res 46: 3306–3317, 2018. doi:10.1177/0300060518781476.
37. Piedmont S, Robra BP. Theory and practice in medical education—expectations and development of skills experienced by students of human medicine compared with students in other disciplines. GMS Z Med Ausbild 32: Doc8, 2015. doi:10.3205/zma000950.