Teaching Homeostasis to Secondary School Anatomy and Physiology Students

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Abstract: In the academic year 2017 - 2018 an informal experiment was conducted with high school students from three Anatomy and Physiology (A&P) classes at Franklin High School in Portland, Oregon. In November of 2017 all 60 students received 90 minutes of instruction on the value of System Dynamics (SD). In December all students built a linear, an exponential, and a simple pharmacokinetic model. Then a subgroup of 13 students met on campus, but outside of class, for one period (60 minutes) per month for the next four months to study homeostasis topics including body temperature, calcium-calcitonin, glucose-insulin, and oxygen-red blood cell production feedback systems. The entire 60 students were given an assessment in May to determine how well the students understood feedback processes and homeostasis. The SD students performed better on the more difficult questions.

The Method: A topic that is central to understanding how the human body functions is the concept of homeostasis. Homeostasis, the process by which the body maintains a myriad of stabilizing dynamics, is difficult for students to understand due to its abstract nature (Assaref et al., 2013; Zion & Klein, 2015). Assaref et al. (2013) indicate that students need to build models of whole systems to help provide students with the systems thinking skills needed to understand the 'mechanisms' behind systemic behavior.

In the academic year 2017 - 2018 an experiment was conducted with high school students from three Anatomy and Physiology (A&P) classes at Franklin High School in Portland, Oregon. In November of 2017 all 60 students received 90 minutes of instruction from Dr. Fisher on the value of System Dynamics. After this introduction, pairs of students used Chromebooks and Stella Online and followed a tutorial to create a simple model to simulate linear increases and decreases in a single stock. In December students examined the dynamics of intravenous (IV) drug infusion. This same model was used to examine a variety of clinical scenarios.

After this introduction students were offered an opportunity to receive honors credit for participating in ongoing system dynamics discussions related to their classroom curricula. This required one class per month for four months (January through April, one 60 minute class per month) meeting outside class with Dr. Fisher and Dr. Gallaher and an obligation to make up the work missed during their absence from the classroom.

<u>January:</u> (Identifying dosing vs metabolic changes from graphs) To model oral drug administration the previous model was extended to include a stomach compartment and first-order transfer from the stomach to the general circulation; blood concentrations therefore illustrated second-order delay behavior. Further examples addressed the influence of absorption. As homework students were told to use the model shown in Figure 1 and given grids with multiple graphs of the drug level in the body of a human and asked if the graph represented a change in drug inflow or drug outflow and how the change came about (increase/decrease in

delivery or metabolism), as would be the case for a medical doctor trying to diagnose a problem with human body function from a time series chart of blood concentrations.

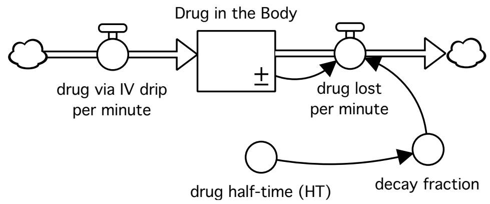


Figure 1: The drug model used to help students experiment with the difference between changing inflow and changing drug half-time graphs.

February: (Body temperature homeostasis; Calcium homeostasis) First a discussion ensued about body temperature homeostasis, with Dr. Gallaher drawing stocks and flows on the board as students indicated components they thought should be included (See Figure 2). Different scenarios involving changing body temperature were presented with questions posed to the students. Discussion followed the design of the stock/flow map for body temperature.

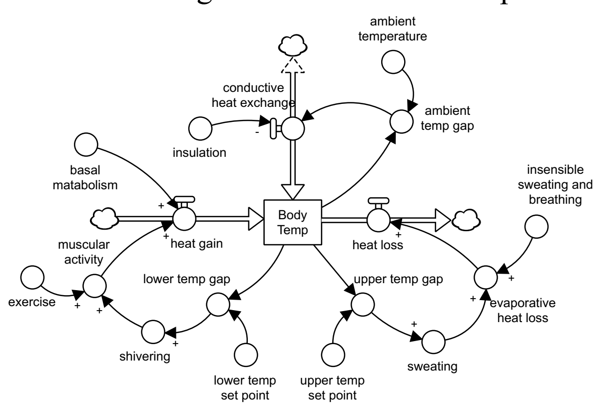


Figure 2: The model diagram created by Dr. Gallaher and students during class.

Next students read a two-page document explaining calcium homeostasis from a systems perspective. While reading the document students were to record, on paper, which concepts should be identified as stocks. The stocks were drawn on the board and students identified the inflows and outflows for the stocks. Finally students reread the document and indicated causal links in the stock/flow drawing on the board. This process evolved toward identifying feedback loops and homeostatic control. Students were asked to determine whether these feedbacks were reinforcing or balancing. As homework students were asked to describe, in their own words, how calcium homeostasis operated.

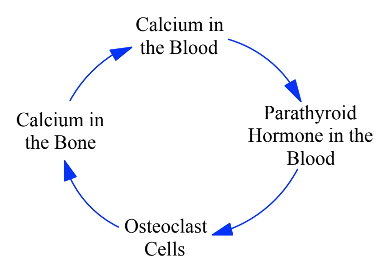
March: (Glucose/Insulin/Glucagon homeostasis) Following a similar procedure to that used for the calcium homeostasis lesson, students read a systems oriented description of glucose/insulin/glucagon homeostasis and were asked to identify the important stocks. Those stocks were drawn on the board and students were asked to identify flows for each stock. After rereading the description students drew causal links in each part of the stock/flow map, leading to identifying the most important feedbacks in this system. Students identified each type of feedback as balancing or reinforcing and how the feedback controlled the homeostatic behavior. As homework students were given a guided model-building lesson and asked to build a small part of a glucose/insulin SD model at home and perform some experiments on the model.

April: (Homeostatic response to the decrease in oxygen in red blood cells) Following a similar procedure to that used for the glucose/insulin/glucagon homeostasis lesson, students read a systems oriented description of oxygen/red blood cells homeostasis and helped build a stock/flow map that eventually highlighted the important feedback in the system and required students to explain how the feedback controlled homeostatic behavior. Since this was the last formal SD lesson students were then asked to fill out a questionnaire about how useful they felt these SD lessons were.

May: (Formal assessment) All students in all three A&P classes (about 60 students) were given an assessment devised by Dr. Fisher and Dr. Gallaher. The assessment asked students to:

1. Differentiate between A&P concepts that might be considered accumulations and those that might be considered rates of change.
2. Answer four simple multiple choice bathtub dynamics questions (i.e., given information about changes in inflow and/or outflow, how will the stock value change?)
3. Interpret, based on a graph of inflow and outflow, whether an accumulated quantity in the body was increasing, decreasing, or remaining the same.
4. Explain whether the given real-world scenario problem (described in the assessment), with a suggested potential solution to the problem, would actually be resolved using the potential solution, and give a reason for their answer.
5. Identify whether a feedback situation (shown as a single causal loop) was positive or negative (words used to describe feedback in their A&P course) and describe why they chose the type of feedback. (2 sub-parts) Note: causal loops were presented in diagrams within the text, so all A&P students had seen this type of representation.
6. Explain the process of glucose-insulin homeostasis in their own words.

Results: Question 5: *The following loop shows one of the feedback cycles for Calcium Homeostasis in the human body. A. Circle they type of feedback represented: (Positive feedback, Negative feedback). B. Explain why you chose the type of feedback you circled. (Blank box provided for handwritten response.)*



SD students: 10 of the 13 SD students correctly identified this loop as a negative feedback loop. Of the correct 10 (77%) negative feedback loop responses:

- five students gave correct reasoning identifying the balancing effect of a negative feedback process.

Control group students: 7 of the 47 control group students identified this loop as a negative feedback loop.
Of the correct 7 (15%) negative feedback loop responses:

- three students gave correct reasoning identifying the balancing effect of a negative feedback to maintain homeostasis.

A very interesting pattern of explanation happened with a significant number of the 30 (64%) students who selected positive feedback.

- Seventeen students indicated it was a positive feedback loop because something was being added within the loop, i.e.:
  - It puts more calcium in the blood.(5 student responses)
  - Nothing is decreasing or taken away in the feedback shown.

- …the calcium and level of osteoclast cells are being evenly replaced.
- Calcium levels respond to changes shown in the cycle (positive changes)…
- Things are getting replaced.
- …as one thing increases the other also increases.
- Calcium is being added and not taken away.
- Each step results in adding something to the next step which moves it positive.
- [the] circle [loop] is constantly increasing things,…

Question 6: *Explain the homeostasis process that occurs in the body when Glucose in the blood is suddenly increased.* (Blank box provided for handwritten response.)

SD students (13):

- Six students (46%) received full credit for their answer, indicating that an increase in glucose will stimulate the release of insulin that will act in a way to reduce the blood sugar level. Some mentioned that insulin is released by the pancreas.

Control group students (47):

- Fourteen students (30%) received full credit for their response.

It was not possible to obtain overall grades for the students in these classes, so it was not possible to obtain a method of evaluating whether the SD group of students was academically similar to the control group of students. That is the main reason a more rigorous analysis of the assessment results could not be completed.

Discussion: A questionnaire was given to the 12 students who were present at the last SD class in April. SD students were able to give a score for each SD activity used over the entire experiment. For the student score on each activity a Likert scale of 1-5 (5 = very helpful) was used. The average score for all students who took most of the SD lessons: Did the lesson help you understand the concepts of systems and physiology? was 4.1. Students were also able to provide comments. 92% of students who took most of the SD lessons said all SD lessons were worth doing. Some student responses were:

- By getting into the harder models I could actually understand what I am doing in class.
- The models reflected real-world scenarios – not just theoretical ones.
- Not only did I learn new things, my understanding of concepts reviewed in class deepened and expanded.
- I learned a lot. It's completely more detailed than A&P [book] on these systems.

Conclusion: Providing System Dynamics lessons for topics that involve systemic interactions, especially prevalent in biology and anatomy and physiology classes, but also in environmental science, global studies, economics, and even mathematics can move students to higher level understanding of complicated problems. The lessons used for this anatomy and physiology experiment involved using stock-flow maps and modeling on the free Stella Online software were well within the reach of the students involved in this experiment and could have been used at any high school. More System Dynamics lessons are needed that fold into the current curriculum of biology, environmental science, global studies, economics and especially mathematics.

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