Use of concept mapping in an undergraduate introductory exercise physiology course

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Physiology is often considered a challenging course (4, 6, 9). Michael (6) suggested three possible factors that contribute to the difficulty of physiology: 1) the nature of physiology, 2) the way physiology is taught, and 3) what students bring to the learning of physiology. Some of the aspects of physiology that make it difficult include the large volume of information typically covered, its integrative nature, and the need for good causal thinking skills to truly understand the material (6). One of the most common complaints heard from students is that there is too much to remember. Students usually make the mistake of trying to memorize hundreds of individual pieces of information, causing them to become overwhelmed and discouraged. It has been stated that it is the job of the teacher to “help the learner learn” (6, 13). One way to do this is to explicitly teach students that physiology actually involves just a few repeating general models (9). More specific physiological concepts can be placed within most of these general models. The existence of these general models should be taken advantage of and used to reduce the perceived volume and help students remember and understand more. Placing physiological concepts into models is a way to organize and “chunk” the information. Chunking is a well-established memory strategy that helps make large amounts of information more manageable and meaningful (14). Another way to chunk information is with a concept map. A concept map is an active learning tool that can be used to graphically organize, structure, and represent information and knowledge in a more meaningful format than text alone (3, 5, 12, 13, 15).

In the process of creating a concept map, students put pieces of information together to create and illustrate the “big picture,” something students often fail to see. As a result, teachers can use concept maps as a tool to guide students into being able to visualize the integrative nature of physiology rather than viewing it as dozens of independent concepts. The construction of concept maps uses higher-level thinking and requires students to identify relationships between concepts that they may not otherwise recognize (13). An exhaustive meta-analysis (11) of studies involving learning with concept maps has revealed that concept mapping is more effective for promoting knowledge retention and transfer than reading text, attending lecture, or class discussion. This difference was attributed to greater learner engagement with concept mapping than with reading or listening (11). In a more recent study (5), concept mapping combined with a mediated learning experience was found to significantly improve problem solving.

One of the general models of physiology is that of control systems, specifically regulation and feedback (9). In addition, it has been suggested that homeostasis is one of the most important, if not the “defining,” core principle of physiology (7, 8). Therefore, I center my exercise physiology course heavily on the concepts of homeostasis and negative feedback. Students are told that homeostasis and negative feedback will be common themes throughout the semester, and they are referred to as often as possible to emphasize this point. They are used as a basis to explain many topics such as reflexes, acid-base balance, blood pressure control, autoregulation, pulmonary ventilation control, exercise recovery, acute responses to exercise, and chronic adaptations to exercise.

The purpose of this report is to describe how I assign concept maps to help encourage students to actively process and organize information into manageable and meaningful chunks and to teach them to recognize the patterns and regularities of physiology. Although there is an extensive amount of literature about the use of concept maps for teaching and learning, there is currently nothing specific to using concept maps in an exercise physiology course. This report is a summary of how I use concept maps in my exercise physiology course at California State University, Northridge.

### Table 1. Basic components of a homeostatic control system

<table>
<thead>
<tr>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory receptor</td>
</tr>
<tr>
<td>Stimulus</td>
</tr>
<tr>
<td>Sensory neurons</td>
</tr>
<tr>
<td>Integrating center</td>
</tr>
<tr>
<td>Motor neurons</td>
</tr>
<tr>
<td>Effector</td>
</tr>
<tr>
<td>Response</td>
</tr>
</tbody>
</table>
mary of my experience using concept maps to teach exercise physiology over the past six semesters. Each semester I have had ~90 students enrolled over 2 different sections of the course. Prerequisite courses include general biology, human anatomy, and human physiology. Students are primarily junior and senior undergraduates majoring in Kinesiology.

Introduction of the General Model: Control Systems

The concepts of homeostasis and negative feedback are introduced early in the semester, and the basic components of a homeostatic control system are established (Table 1). The commonly relatable analogy of a home thermostat is used to apply the concepts and illustrate homeostatic control and its basic components. Students easily recognize that the thermostat is set to a predetermined temperature and that a change in room temperature is the stimulus that disrupts homeostasis and triggers a negative feedback response to negate the stimulus and bring the temperature back to its set point.

Introduction to Concept Mapping

Some students have a difficult time learning to develop concept maps, and this is likely due to previous emphasis on rote-mode learning (13). It is often a challenge for students to transition from rote mode learning to meaningful learning. Novak and Canas (13) recommended beginning with a knowledge domain very familiar to the student. As mentioned above, the home thermostat is a relatable concept and, therefore, is a good first example of a control system illustrated as a concept map (Fig. 1). To reinforce the basic components of a homeostatic control system, I color code the components and include a legend. Michael (6) stated that teachers must first model the kind of reasoning we expect them to do, and this is good for that purpose. Novak and Canas (13) recommended choosing a limited domain of knowledge for the first concept map. Homeostatic control systems can be very simple or very complex. There can be one or more sensory receptors, effectors, responses, and/or levels of responses. The thermostat map is relatively simple, with one receptor, two responses, and only one level of responses.

Throughout the semester, on the chalkboard, I often draw concepts and connect them with arrows to other concepts to reinforce causal relationships. We repeatedly discuss another one of the core principles of physiology: causal mechanisms (7, 8). I emphasize that everything that occurs in the human body does so for a reason, and if you can figure out the reason, it will make remembering much easier. I encourage students to “find the logic.” Instead of trying to remember everything that happens, they should learn to reason out what should happen and why. I tell them that to truly understand physiology is to know why and how (by what mechanism) things happen, not just what happens. Anyone on the street can tell me that their heart rate increases when they exercise, but few can tell me why or the physiological mechanism that causes the increase. By the time the first concept map is assigned, students have

Table 2. Concept map general guidelines

| Put the map on one side of one sheet of paper. |
| Put each concept in a separate box. |
| Connect associated boxes with lines and include arrowheads on each connection to indicate the sequence order and/or causal relationship between the concepts. |
| Insert a linking word or words over each connection to clearly indicate the relationship between the concepts in the two connected boxes. The linking word(s) should create a sentence that links the two connected concepts. Check each connection by reading the sentence to yourself. |
| When applicable, indicate whether the concepts in the boxes increase or decrease. |
| Do not use abbreviations other than those used in the textbook and on lecture slides. |
| Do not cross any lines or repeat any boxes. |
become accustomed to identifying causal relationships and seeing them written out as a series of concepts connected with arrows. This practice during lecture serves as a scaffold for the creation of concept maps that illustrate causal relationships. If created thoughtfully, concept map assignments provide an opportunity for students to practice their reasoning skills and the application of some of the general models and core concepts of physiology. It is this type of practice and subsequent

Map the sequence of acute physiological events (negative feedback) that are triggered in response to a drop in blood pressure and eventually cause blood pressure to increase back to normal.

- On your map, include all of the control system components (listed below)
- Only include factors that contribute to an acute increase in blood pressure
- Using the colors specified below, outline the boxes to indicate the control system component
- On the same page as the map, draw a key/legend listing the components and corresponding colors

Control System Components & Colors

1. **Stimulus** (red) – one box at top of map
2. **Sensory Receptor** (pink) – one box
   - Include receptor type & location(s)
3. **Sensory Neuron** (orange) – one box
4. **Integrating Center** (yellow) – one box
   - Specify the location within the central nervous system
5. **Autonomic Neurons** (green) – one box per neuron, two boxes total
   - Specify the two branches of the autonomic nervous system
   - Specify whether the output through each neuron increases or decreases
6. **Effectors** (blue) – one box per effector, three boxes total
7. **Responses** – one box per response
   - Indicate whether the specific responses increase or decrease
   - Indicate each direct **Effector Response** (purple) – one response per effector
   - Indicate each **Secondary Response** (brown) that occurs as a result of the effector responses
     - Note: there will be two or more levels of secondary responses after each effector response
     - Indicate the **Final Result**; this opposes the original stimulus and completes the negative feedback loop (one black box at the bottom of the map)

*Include the formulas we have learned in class. For example, three of the variables that will be on the concept map are PR, Q, and BP. Each of these has an associated formula. When you put each of these in a box, also include its formula. For example, in the box containing BP, also write BP = PR \times Q. This makes it clear that PR and Q have a direct effect on BP, and therefore they will likely be in the boxes just above, and lead to a change in BP.*

Fig. 2. Blood pressure (BP) concept map assignment. PR, peripheral resistance; Q, cardiac output.
feedback that fosters the very skills that students tend to lack and that contribute to their difficulty with physiology. Concept map assignments often reveal student misunderstandings and misconceptions and therefore afford extra teachable moments. If maps are assigned, graded, and returned before an exam, students have more opportunities for the information to fall into place. It is unlikely that students will process the information this deeply while studying on their own.

All of the concept maps assigned over the semester start with the same set of general guidelines (Table 2). Each assignment includes an intentional amount of assistance and complexity. Subsequent assignments contain less assistance and/or more complexity to increase the challenge as the students become more accustomed to creating concept maps. Most students do their maps by hand, but they are also given the option of using IHMC Cmap Tools, a free concept map software program available at http://cmap.ihmc.us/download.

**Concept Maps**

**Concept map 1: blood pressure.** The first concept map assignment is to illustrate the acute control of blood pressure. Since this is the first map the students create on their own, and since it is more complex than the thermostat map, a lot of assistance and scaffolding are included in the assignment (Fig. 2).

For a concept map to be meaningful, students must possess the relevant prior knowledge (13). Therefore, before this concept map is assigned, we cover an entire chapter on the cardiovascular system, including a thorough discussion of the basic formula for mean arterial blood pressure (blood pressure = PR × Q, where PR is peripheral resistance and Q is cardiac output). Students learn that anything that affects blood pressure does so through either PR or Q. Therefore, anything that contributes to bringing blood pressure back to normal could be due to a change in PR or Q. To optimize control and provide a back up in case of system failure, the body usually initiates multiple responses that work toward a central goal. In the case of acute blood pressure control, both PR and Q are affected. To help students understand that anything affects blood pressure does so through either PR or Q, we discuss the following formulas: PR = [(L × blood viscosity)/r^4] and Q = (stroke volume × heart rate), where L is the vessel length and r is the vessel radius. It should be noted that Poiseuille’s law states that resistance to flow is equal to 8Lη/r^4 (where η is fluid viscosity). However, because 8/π is a constant, it can be removed from the equation to simplify the relationship. In addition to discussing the formulas, we also cover the individual variables within the formulas in detail. Students are required to include these formulas on their concept map to help them visualize the application of the formulas and to learn to use them to piece the relationships together. As we discuss the relationships within the map, I write parts of the map on the board. I do not, however, assemble the completed map. For example, I may draw a short portion of the map, about four factors in length (e.g., ↑ Sympathetic neuron output → Arteriole and venous smooth muscle → Smooth muscle contraction → ↓ Vessel radius). As I draw, I verbalize the relationships between factors; I do not write the linking words on the board. My goal is to demonstrate relationships and how to link concepts without giving the students too much. The concept map assignments should be challenging and not just an exercise of recopying their lecture notes. The model blood pressure concept map is shown in Fig. 3.

**Concept map 2: stroke volume.** The second concept map assignment is to illustrate the acute control of stroke volume during cardiorespiratory endurance exercise. This map is assigned after the completion of a chapter on cardiorespiratory responses to acute exercise. For this map, students are provided with the top of the map and the list of concepts that will be on the map (Fig. 4). Although this map illustrates control systems, the students are not required to include all of the homeostatic control system components, as they did for the blood pressure map. This modification reduces the complexity of the map and focuses their attention on the physiological responses. As a result, there is almost no variability in the linking words. I want the students to recognize that a series of causative events occur and that one event “causes”...
Map the acute responses that cause stroke volume to increase during large muscle cardiorespiratory endurance exercise.

- Box at top of map: Initiation of Exercise (use the figure below as a starting point)
- Box at bottom of map: Increase in Stroke Volume
- Include all of the factors listed below on the map

**Factors**

<table>
<thead>
<tr>
<th>Afterload</th>
<th>Muscle arteriole vasodilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure gradient (left ventricle to aorta)</td>
<td>Peripheral resistance (include formula)</td>
</tr>
<tr>
<td>End diastolic volume</td>
<td>Preload</td>
</tr>
<tr>
<td>Left ventricular contractility</td>
<td>Respiratory pump effect</td>
</tr>
<tr>
<td>Left ventricular contraction strength</td>
<td>Skeletal muscle pump</td>
</tr>
<tr>
<td>Muscle arteriole autoregulation</td>
<td>Venoconstriction</td>
</tr>
<tr>
<td>Muscle arteriole radius</td>
<td>Venous return</td>
</tr>
</tbody>
</table>

![Fig. 4. SV concept map assignment.](http://advan.physiology.org/)

Another, which causes another, etc. In the past, I did not require linking words and realized that some students did not understand the relationships between the concepts. In addition, they often put the concepts in the wrong order. Although the linking words in this map (and the next) are almost always “causes”, the inclusion of these words helps repetitively reinforce the causative sequential process. The model stroke volume concept map is shown in Fig. 5. Notice on this map that the relationship between afterload and stroke volume is attributed to a pressure gradient. This is an example of another one of the general models in physiology, mass and heat flow, and another core principle, flow down gradients (7, 9). Flow down gradients is another concept that comes up repeatedly throughout the semester. As with homeostasis and negative feedback, I refer to it often to underscore that physiology is made up of repeating models and principles. Mass and heat flow down gradients are used as the basis to explain topics in the course such as blood flow, air flow, gas diffusion, and thermoregulation.

**Concept map 3: cardiorespiratory endurance exercise adaptations.** A large portion of exercise physiology curriculum concerns how the body responds to exercise training. The most widely used measurement in exercise physiology is the maximal O$_2$ consumption test (1). Therefore, the capstone concept map in the course is a map of the adaptations to cardiorespiratory endurance training that contribute to an increase in maximal O$_2$ consumption. This map is assigned at the end of the semester, but there is enough time available to grade and return them to students before the final exam. The stroke volume map overlaps largely with this map and therefore serves as a partial scaffold. The overlap also allows students to build on prior knowledge and to see the repetitive nature of the material.

The basis for this map is the Fick equation, which states the following: O$_2$ consumption = (Q $\times$ arterial-venous oxygen difference). The students are given the bottom of the map, which illustrates the Fick equation. Students are, again, provided with the list of concepts (Fig. 6). For this map, it is particularly useful to supply students with the list to define the breadth and depth of the map. Without this guidance, students will create maps that range from very simple to very complex. The detail possible on this map is almost unlimited. Providing the list also helps to make the assignment more objective. Objectivity helps with grading and is particularly useful in an introductory level course to provide the desired level of difficulty and minimize frustration among the students. The most challenging aspect of mapping is thought to be connecting concepts and choosing linking words, which require conceptual understanding and knowledge structuring (13, 16). Therefore, it is likely that supplying the list does not detract significantly from the learning process. The model maximal O$_2$ consumption concept map is shown in Fig. 7.

**Concept Map Scoring Rubric**

Scoring concept maps can be difficult due to the large diversity that can be seen within the maps of individuals. As mentioned...
above, by including the list of concepts, the assignment becomes more objective. I use the same rubric for each concept map assignment (Table 3). Students are not penalized for including extra concepts, as long as the connections are accurate and there are not any crossed lines. If all of the concepts in the given list are included, it is possible to draw the map without any crossed lines. Crossed lines are prohibited because they detract from the readability of the map. Before this rule was implemented, students sometimes created maps that were, simply stated, a mess. Although the inclusion of this rule limits the number of concepts that can be added, I feel the outcome is a more clean, organized, and usable tool. In addition, students often have to redraw their maps two or more times to create a map without crossed lines. Although this makes the process more time consuming, the repetition is likely beneficial to the learning process. For linking words, credit is given as long as there is a linking word included and it clearly illustrates an understanding of the relationship between the connected concepts.

Students’ Perceptions of Value

Students have been found to value concept maps the most when the assignments are 1) designed to meet educational goals, 2) given timely feedback, and 3) clearly aligned with
Map the adaptations to large muscle cardiorespiratory endurance training that contribute to an increase in maximal oxygen consumption ($\dot{V}O_{2\max}$).

- Box at top of map: Cardiorespiratory Endurance Training
- Directly under the Cardiorespiratory Endurance Training box will be 12 different adaptations (from the list below)
- Bottom of map: The Fick equation (use figure below)
- Include all of the factors listed below on the map
- Do not shorten the factor names to the extent that they lose their specific meaning (e.g. diffusion rate instead of capillary $O_2$ diffusion rate)
- Keep in mind the formulas for Fick’s Law of Diffusion and peripheral resistance, and the stroke volume concept map
- Assume the individual is not an elite endurance athlete

**Factors**

- % blood flow distribution to active muscle
- Active muscle blood flow volume
- Aerobic ATP production rate
- Afterload
- Autoregulation by active muscle
- Blood pressure gradient (LA to LV)
- Blood pressure gradient (LV to aorta)
- Blood viscosity
- Breathing frequency rate
- Capillary $O_2$ diffusion area
- Capillary $O_2$ diffusion rate (include formula)
- End diastolic volume
- LV contractility
- LV contraction strength
- LV pressure
- LV hypertrophy
- LV internal diameter
- Mitochondrial size & number
- Muscle capillary density & recruitment
- Muscle arteriole radius
- Muscle $PO_2$
- Myoglobin content
- $O_2$ delivery volume to active muscle
- $O_2$ usage rate
- Oxidative enzyme activity rate
- Peripheral resistance (include formula)
- Plasma volume
- $PO_2$ pressure gradient (capillary to muscle)
- Preload
- Red blood cell volume
- Respiratory pump effect
- SNS output to inactive tissues
- Stroke volume
- Tidal volume
- Total blood volume
- Vasoconstriction to inactive tissues
- Vasodilation to active muscle
- Venous return
- Ventilation rate

**Fig. 6.** Cardiorespiratory endurance exercise adaptations concept map assignment. $\dot{V}O_{2\max}$, maximal (max) $O_2$ consumption; LA, left atrium; LV, left ventricle; SNS, sympathetic nervous system; $AVO_2$ diff, arterial-venous $O_2$ difference.
exams and other forms of assessment (2). I often point out to students that several pages from their textbook can be reduced to a one-page concept map. In the case of the cardiorespiratory endurance training adaptations map, most of the major concepts from an entire chapter can be mapped onto one standard sheet of paper. The assignments are designed to encompass large amounts of the most important course material, and this is explicitly expressed. As students decide whether to complete an assignment and how much effort to exert, these factors are likely to positively influence their decisions.

Concept maps are always assigned so that they can be graded and returned before the exam that covers that material. In most cases, maps are returned in 1 wk. I place much emphasis on the importance of the concept maps and often put portions of the maps on the exams.

Over two semesters, students in my exercise physiology courses were surveyed at the end of the semester to provide information about their study habits and preferences for the course. The response rate was very high. Of 182 students, 171 students (94% for both semesters) completed the survey. As part of the course materials, I have developed a workbook of practice questions and activities to assist and guide students when studying for exams. The workbook contains nine differ-

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**Fig. 7.** Cardiorespiratory endurance exercise adaptations concept map. **A**, capillary $O_2$ diffusion area; **V$_{gas}$**, gas diffusion rate; $D$, gas diffusion coefficient; $P_1$, gas pressure at location 1; $P_2$, gas pressure at location 2; **T**, diffusion tissue thickness.

Table 3. **Concept map scoring rubric**

<table>
<thead>
<tr>
<th>Total points possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure map: 20 points</td>
</tr>
<tr>
<td>Stroke volume map: 20 points</td>
</tr>
<tr>
<td>Cardiorespiratory adaptations map: 30 points</td>
</tr>
</tbody>
</table>

**Point deductions**

- 0.5 points for each misspelled word
- 1 point for each
- Missing concept
- Incorrect or missing connections between boxes
- Incorrect or missing linking word(s) between boxes
- Incorrect or missing concept descriptions (i.e., increase vs. decrease)
- Other guideline errors (map on >1 page, no boxes, no arrowheads, crossed lines, repeated boxes, etc.)
DISCLOSURES

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

AUTHOR CONTRIBUTIONS

Author contributions: K.H. conception and design of research; K.H. performed experiments; K.H. analyzed data; K.H. interpreted results of experiments; K.H. prepared figures; K.H. drafted manuscript; K.H. edited and revised manuscript; K.H. approved final version of manuscript.

REFERENCES


How We Teach

Conclusions

Physiology is difficult for students, likely due to 1) its nature, 2) the way it is taught, and 3) what students bring to the classroom, including their prior knowledge, skills, and thoughts on learning (6). Assigning concepts maps is a way to target and minimize all three of these. By nature, physiology courses are largely integrative, typically cover a large volume of information, and require causal thinking. Students are overwhelmed by the volume and struggle with causal and integrative thinking. In addition, students typically attempt to learn through memorization. These factors make for a bad combination. It is up to teachers to help learners learn (6). In physiology, we can do this by emphasizing general models, by teaching core principles, and by assigning concept maps. A concept map is an active learning tool that can be used to graphically organize, structure, and represent information and knowledge in a more meaningful format than text alone. While creating concept maps, students draw the integrative nature of physiology and are pressed to identify causal relationships. In the process, students practice higher-level thinking and reasoning skills.

Table 4. Postexam survey

<table>
<thead>
<tr>
<th>Question 1. As you took the exam today, did you ever draw portions of a concept map to help you answer a question?</th>
<th>Number of Responses</th>
<th>Percentage of Total Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>40</td>
<td>32.5</td>
</tr>
<tr>
<td>Yes</td>
<td>75</td>
<td>61.0</td>
</tr>
<tr>
<td>Did not draw, but did visualize</td>
<td>8</td>
<td>6.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 2. Please rate the following statement on a scale from 0 to 5 (choose 0 if you did not complete any of the concept maps): the blood pressure and stroke volume concept maps that I completed for class helped me answer the questions on this exam.</th>
<th>Number of Responses</th>
<th>Percentage of Total Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 (very true)</td>
<td>59</td>
<td>48.0</td>
</tr>
<tr>
<td>4</td>
<td>29</td>
<td>23.6</td>
</tr>
<tr>
<td>3 (somewhat true)</td>
<td>24</td>
<td>19.5</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>3.3</td>
</tr>
<tr>
<td>1 (not true at all)</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>0 (not applicable)</td>
<td>4</td>
<td>3.3</td>
</tr>
</tbody>
</table>

n = 123 total respondents.


