Core Concepts for Anatomy and Physiology: A Paradigm Shift in Course and Curriculum Design

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Core Concepts for Anatomy and Physiology: A Paradigm Shift in Course and Curriculum Design

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Abstract

The vast amount of information in the average anatomy and physiology course poses a challenge for instructors and students alike. Yet, studies show that students understand, retain, and transfer knowledge most effectively when courses emphasize depth over breadth. But, sacrificing breadth requires judiciously choosing which topics to teach. In this article we describe a potential curricular focus that may guide our choices: concentrating on core concepts. Also described by terms such as core principles, big ideas, or common themes, we define core concepts as foundational principles relevant to multiple situations that can be used to make predictions. Core concepts can help guide the design of our curriculum, class activities, and assessment in order to facilitate lasting, meaningful, and transferable student learning. doi: 10.21692/haps.2017.017

Key Words: core concepts; physiology; curriculum development; course design; inquiry learning

Introduction

As educators, the two questions that most inform our everyday practice are "what should I teach? and "how should I teach it?" The "how" of classroom science teaching has historically centered on lecture with varying degrees of visual aids (transparencies, Powerpoint, and now Youtube videos). The instructor is the curator and provider of information, while the students listen, take notes, and ask occasional unprompted questions. However, as the field of science education research has matured, the limitations of traditional lecture have become increasingly apparent (Bransford *et al.* 1999). Other instructional methods, often generalized as "active learning" have shown to be more effective at promoting deeper, more transformative (conceptual) learning (Michael 2006). The landmark meta-analysis of Freeman *et al.* (2014) analyzed these and other studies comparing the effectiveness of the two approaches to teaching, and their findings were clear: Active learning wins; lecture loses.

While considerable work remains to be done in terms of refining how we teach, we would like to focus here on the first question: What should I teach? Anatomy and physiology is a scientific discipline rich in detail and facts. Historically, our ability to recall those details and facts has been equated with our understanding of our discipline. Online test banks still quiz students about the volume of urine produced by the kidney per day (McGraw Hill Education 2017), or the number of secondary bronchi (Biology Online 2017). We now know that recall is not the same as understanding.

Studies show that students understand, retain, and transfer knowledge most effectively when courses emphasize depth over breadth (Schwartz *et al.* 2009). But, now that we cannot teach everything in a shallow fashion, the question of What to Teach becomes even more difficult to answer. In this article we describe a potential curricular focus that may guide our choices: concentrating on *core concepts*. Also described by terms such as *core principles, big ideas,* or *common themes,* we define core concepts as foundational principles relevant to multiple situations that can be used to make predictions. Using key concepts fosters understanding and retention, and allows knowledge to be transferred between different domains (Michael *et al.* 2017).

Core Concepts in Science Education

Organizing curriculum around core concepts is not a revolutionary idea; this approach (alongside active learning) is advocated by policy documents addressing teaching and learning at all levels (K-16) and all STEM disciplines. Starting with the most general and transitioning to more Biology-centered lists, examples include:

1. New Generation Science Standards (NGSS) proposes 7 "cross-cutting concepts" relevant to all STEM fields, and describes how student understanding of each idea should develop over the course of K-12 education (NGSS Lead States 2013).

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2. Scientific Foundations for Future Physicians recommends that pre-medical programs emphasize competencies rather than specific content (Association of American Medical Colleges and the Howard Hughes Medical Institute 2009).
3. NRC BIO2010: Transforming Undergraduate Education for Future Research Biologists (2003) describes 18 central themes (National Research Council 2003).
4. Vision and Change has five core concepts: Evolution, Energy and Matter, Information flow, Structure and function, and Systems (AAAS 2010).
5. The NSF sponsored "Conceptual Assessment in the Biological Sciences (CAP)" proposes eight core concepts, adding homeostasis, cell theory, and causal mechanisms to the Vision and Change list (Michael *et al.* 2008).

So, instructors of first-year biology courses have multiple (yet largely consistent) lists of key concepts to guide them. The onus is now on instructors of more specialized courses in the biological sciences to derive their own lists. Some research groups have written preliminary lists to guide the development of *concept inventories,* which are validated assessment items that measure conceptual understanding and diagnose misconceptions (Garvin-Doxas *et al.* 2007). It was in the attempted development of a concept inventory for physiology that the research group of Joel Michael, William Cliff, Jenny McFarland, Harold Modell and Ann Wright realized the need for a list of key concepts in Physiology. After a decade of work and multiple preliminary publications, they published their landmark monograph in 2017: the Core Concepts of Physiology (Michael *et al.* 2017).

Core Concepts in Physiology: the Conceptual Assessment of Physiology (CAP) Group

The process by which Michael and colleagues came up with their list of Physiology core concepts is comprehensively described in their monograph (Michael *et al.* 2017) and in a shorter article (Michael and McFarland 2011). In brief, a small group of educators involved in the Conceptual Assessment in Biology project developed an initial list of nine physiology core concepts (Michael *et al.* 2009). Following consultations with a wide variety of educators, they expanded the list to include the fifteen core concepts shown in Table 1 (Michael and McFarland 2011). These concepts include relatively concrete concepts (e.g. flow down gradients), broad themes (e.g. physics/chemistry), and soft skills (e.g. scientific reasoning).

In order to render core concepts useful to educators, three highly ranked core concepts were selected for additional development: flow down gradients, homeostasis, and cell-cell communication. Each was 'unpacked' into a validated *conceptual framework*, a hierarchical list of component concepts and sub-concepts (McFarland *et al.* 2016). For instance, one of the five homeostasis components is *Homeostatic processes require a sensor inside the body;* a sub-concept is *Sensors are always active.* They accompany each list with definitions, visual representations, and relevant physiologic situations, everything instructors need to fully understand the concepts. (Later in this article we discuss ways to use the core concepts in teaching). The remaining twelve concepts have not yet been unpacked, and Michael *et al.* (2017) have called on the physiology community at large to continue these efforts. However, even now their list of core concepts can serve as a framework for structuring our courses and even our exams.

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Table 1: Core Concepts of Physiology (Michael *et al.* 2017)

Core Concept	Explanation
Evolution	The mechanisms of evolution act at many levels of organization and result in adaptive changes that have produced the extant relationships between structure and function.
Homeostasis	The internal environment of the organism is actively maintained constant by the function of cells, tissues, and organs organized into negative feedback systems.
Causality	Living organisms are causal mechanisms ("machines") whose functions are explainable by a description of the cause-and-effect relationships that are present.
Energy	The life of the organism requires the constant expenditure of energy. The acquisition, transformation, and transportation of energy are essential functions of the body.
Structure/function	The function of a cell, tissue, or organ is determined by its form. Structure and function (from the molecular level to the organ system level) are intrinsically related to each other.
Cell theory	All cells making up the organism have the same DNA. Cells have many common functions but also many specialized functions that are required by the organism.
Levels of organization	An understanding of physiological functions requires understanding the behavior at every level of organization from the molecular to the social.
Cell-cell communication	The function of the organism requires that cells pass information to one another to coordinate their activities. These communication processes include endocrine and neural signaling.
Cell membrane	Cell plasma membranes are complex structures that determine what substances enter or leave the cell. They are essential for cell signaling, transport, and other processes.
Flow down gradients	The transport of "stuff" (ions, molecules, blood, and gas) is a central process at all levels of organization in the organism, and a simple model describes such transport.
Genes to proteins	The genes (DNA) of every organism code for the synthesis of proteins (including enzymes). The genes that are expressed determine the functions of every cell.
Interdependence	Cells, tissues, organs, and organ systems interact with one another (are dependent on the function of one another) to sustain life.
Mass balance	The quantity of "stuff" in any system, or in a compartment in a system, is determined by the inputs to and the outputs from that system or compartment.
Physics/Chemistry	The functions of living organisms are explainable by the application of the laws of physics and chemistry.
Scientific reasoning	Physiology is a science. Our understanding of the functions of the body arises from the application of the scientific method; thus, our understanding is always tentative.

Core Concepts for Anatomy and Physiology

While the CAP list has been validated and has received widespread acceptance, many of us teach combined courses in Introductory Anatomy and Physiology. To this end, the Human Anatomy and Physiology Society (HAPS) has developed a list of Fundamental Process and Learning Goals that are meant to "form the unifying foundation for all topics in anatomy and physiology and are to be emphasized throughout Anatomy and Physiology I and II" (HAPS 2017a). This list is composed of eight goals and includes items such as "Develop a vocabulary of appropriate terminology to effectively communicate information related to anatomy and physiology", and "Interpret graphs of anatomical and physiological data". HAPS also includes an additional three "broader process goals" that are meant to stress skills developed throughout a curriculum (HAPS 2017a). One example of these is "Demonstrate information literacy skills to access, evaluate, and use resources to stay current in the fields of anatomy and physiology". Although there is some overlap between the Core Concepts in Physiology and the HAPS Learning Goals, the latter are quite general and emphasize transferable skills.

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In an attempt to identify content-based core concepts in Anatomy, one of us led a workshop at the 2015 HAPS Annual Meeting (Jensen 2015). The participants identified three potential anatomy-specific additions to the CAP list: Inside vs. outside, medical terminology, and body spaces and cavities. However, aside from this preliminary work, we are not aware of any published list of Core Concepts for Anatomy and Physiology, either validated or invalidated. Moreover, Michael *et al.* (2017) acknowledge that instructors generally pick-and-choose which concepts they will emphasize. Instructors may thus want to develop their own list of core concepts to scaffold their courses. For example, Table 2 outlines the "key ideas" developed by one of us to guide textbook authorship activities. This preliminary effort can provide an optional starting point for instructors until the A & P community develops a consensus list.

Table 2: Examples of Key Ideas of Anatomy and Physiology

Key Idea	Explanation
1. Structure-Function	The anatomy (structure) of an element impacts its physiology (function).
2. Levels of Organization	All living things are organized from very simple levels (e.g., atoms) to very complex levels (e.g., an organism). Anatomy and physiology can be studied at any of these levels.
3. Homeostasis and Negative Feedback	Despite changing environmental conditions, critical body functions such as blood pressure and temperature are maintained within tight limits. Negative feedback is a control system based on information returning to a source. It reverses any upward or downward shift in a particular body condition. Negative feedback loops require a sensor, control center, and effector.
4. Barriers	Barriers help the body maintain distinct environments. For instance, the skin and mucous membranes separate the inside of the body from the external environment, and the plasma membrane separates the cytosol from the extracellular fluid.
5. Gradients and Flow	The movement (flow) of a particular substance is promoted by gradients and opposed by resistance.
6. Water	Water participates in many physiologic processes. Understanding its characteristics (e.g. conductivity, ability to act as a solvent) is key to understanding these processes.
7. Enzymes and Chemical Reactions	Most chemical reactions require the actions of enzymes. The activity of specific enzymes can be increased or decreased in response to changing body conditions. The concentrations of reactants can also alter the speed and, in some cases, the direction of the chemical reaction.
8. Energy	Organisms need to generate and use energy. Tracking energy and matter flow through systems is a key part of understanding physiology.
9. Genes Code for Proteins	DNA is the cell's master blueprint, determining the body's structures and functions. Mutations, changes in the DNA sequence of a gene, can change the shape of the resulting protein, or even stop it from being synthesized.
10. Causation and Correlation	Two events may be correlated (i.e., frequently occur together) without one event causing the other. Establishing causation involves specifying a sequence of interactions linking the cause to the effect.
11. Adaptation	Organisms *adapt* to the environment; that is, their structure, function, or behavior changes in response to changes in their environment. Adaptation often results from injury, and helps protect against future damage.
12. Communication	The body uses chemical and electrical signals to convey information. Chemical signals alter the activity of target cells by binding specific receptors.
13. Mass Balance	The amount of material in a system depends on both inputs and outputs. With few exceptions, the adult body keeps storage pools of most substances relatively constant by matching input and output.

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Core Concepts vs. Learning Outcomes

Key concepts are distinct from learning outcomes, which are hierarchical lists of tasks students should be able to perform using important concepts and facts, generally organized by body system. A given key concept is relevant to multiple learning outcomes. The American Physiology Society (APS) and the Human Anatomy and Physiology Society (HAPS) have invested considerable effort in developing comprehensive lists of learning objectives and outcomes for physiology and anatomy and physiology, respectively (Carroll 2016; HAPS 2017b; HAPS 2017c). Each specific learning outcome is associated with a cognitive level, as defined in an accompanying document (HAPS 2017d). Since learning outcomes are manifestations of key concepts in different body systems, it is possible to link them to both process-oriented learning goals and content-oriented key concepts. For instance, 11 specific learning outcomes within the Homeostasis module (module B) are linked to HAPS Content Goal 3 (Recognize and explain the principle of homeostasis and the use of feedback loops to control physiological systems in the human body). Considering the CAP key concepts, the *Flow down gradients* key concept applies to HAPS outcomes relating to diffusion (C.8.1), action potentials (H.4), blood pressure (K.14) and pulmonary ventilation (M.3).

Core Concepts: From Theory to Practice

Core concepts can help guide the design of our curriculum, class activities, and assessment in order to facilitate lasting, meaningful, and transferable student learning. Instructors can decide when and how to introduce their selected core concepts; introducing too many concepts at the beginning of the course may be overwhelming. One of us (Hull) introduces three concepts (homeostasis, mass balance, and flow down gradients) in the first week of physiology class, using a group exercise derived from Harold Modell's work (Modell 2000). Other core concepts are introduced as needed. For instance, stability and change (an NGSS key concept) is presented during the discussion of the bicarbonate reaction in the respiratory system unit. Conversely, one of us (Jensen) organizes an entire introductory course around the key concept of homeostasis.

The core concepts, alongside the relevant published learning outcomes (APS or HAPS), can also guide the choice of which topics to cover. Michael *et al*. (2017) recommend that the use of core concepts be reflected in course learning outcomes. We propose that they could also be used to pare down learning outcomes; if the outcome does not address a core concept, is it really that important?

The design of learning resources can similarly be organized around core concepts. Michael *et al*. (2017) provide a model for this process. They describe active learning techniques that incorporate core concepts into the teaching of three important, yet difficult, topics: acute blood pressure regulation, ventilation, and the hypothalamo-pituitary axis. Michael *et al*. note, "What is needed is the development of learning resources that focus on core concepts as well as on specific physiological mechanisms" (Michael *et al.* 2017 p.149). While they are not coded for particular key concepts, the HAPS Teaching Tips database (HAPS 2017e) contains many active learning resources to help address this need. The authors of this article are developing guided inquiry lessons on topics such as the regulation of blood pressure, and membrane physiology. Our long-term goal is to provide HAPS members with a library of curriculum materials that:

1. Address the core concepts and HAPS learning outcomes.
2. Promote good conversation among students.

To this end we are welcoming submissions for a Special Fall issue of the *HAPS Educator*, which will focus on curriculum. See the full announcement on page 152.

(Click Here to go to the full announcement)

If used to guide curricular materials, core concepts should also guide assessments. As mentioned earlier, Michael *et al*. embarked on their Key Concept project as a means of producing validated assessment tools. Due to the sheer magnitude of work involved in this process, they have only produced a Homeostasis concept inventory (HCI) (McFarland *et al.* 2017). The questions can be used as models for the development of questions examining other key concepts chosen for a specific course.

A final consideration relates to the organization of the course itself. Michael *et al.* (2017) presume the classical systems-based approach to both textbook and course design; they emphasize that "... progress in learning of the core concepts of physiology ought to occur in parallel" (Michael *et al.* 2017 p.138). An interesting thought exercise is to consider moving away from body systems and towards core concepts. What would a book look like that was organized around core concepts instead of systems? What would a course look like? As we (the authors) have begun discussing these questions, we are aware of the power of "teaching the way we were taught". Perhaps the systems approach is the most viable one, however, as scientists, we hesitate to draw this conclusion without investigating the possibility of alternate approaches.

Conclusion

The enormity of content in anatomy and physiology makes these courses challenging for both instructors and students alike. It is easy to think that nearly all the information contained in a textbook is important, but evidence suggests that deep learning results from understanding relationships between content items. Although many instructors have used the phrase "this is analogous to..." when comparing one system with another, we wonder how a course would change if taught from the perspective of analogous topics driven by

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core concepts. Such intentional design might change some courses a lot, and others a little. We think it is a discussion worth continuing and a concept worth trying.

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In addition to their individual research interests, they are collaborating on a research project developing and evaluating guided inquiry activities for upper-level physiology courses.

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