Student thinking about core physiology concepts across a physiology major

Chancellor's Award Faculty Grant

Katharine Semsar, PhD
Molecular, Cellular, and Developmental Biology

Summary
With this proposal, I am seeking continuation funding to analyze and extend data collected during the construction and validation of Phys-MAPS, a programmatic physiology assessment. The Phys-MAPS was developed as an assessment to align with nationally recognized core concepts in biology and physiology. Having these programmatic learning goals and assessment now in place, we can follow the principles of backward design to identify and develop instructional materials to help student meet these programmatic conceptual learning goals. Understanding both the prior knowledge students have coming into physiology programs and the misconceptions students continue to hold when graduating from physiology programs is essential to designing effective instructional approaches. Using data on student thinking from our national pilot of the Phys-MAPS assessment and previously-conducted student interviews, the goal of this proposal is to summarize student thinking on core physiology concepts across a physiology curriculum and provide suggestions for instruction to address persistent student misconceptions. Having these data on student thinking available will benefit physiology curricula development both nationally and here in CU's Integrative Physiology department.

Introduction
With the publication of AAAS's *Vision and Change* report in 2011, a backward design approach to biology curricula can begin on a national scale. Backward design is a general model of instruction design comprised of three sequential parts: 1) setting learning goals, 2) deciding on what achievement of those learning goals looks like, and 3) designing instructional activities to help students achieve those goals (Wiggins and McTighe, 1998). As the first step in backward design, the *Vision and Change* report defined goals for conceptual learning in undergraduate biology education by delineating five core concepts of biology that apply across sub-disciplines of biology, including physiology.

The second step of backward design is identifying and/or creating assessments that can measure student learning. As no programmatic assessments of biology concepts yet existed, a multi-institutional collaboration, including Dr. Jennifer Knight here at CU Boulder, established the Bio-MAPS (Biology - Measuring Achievement and Progression in Science) Project to: 1) translate the Vision and Change concepts to the sub-disciplines of biology (BioCore Guide; Brownell et al., 2014) and 2) build conceptual programmatic assessments aligned with Vision and Change core concepts.

As a member of the Bio-MAPS team, I led the construction and validation of the physiology assessment, Phys-MAPS. This assessment is focused on Vision and Change concepts as they relate to physiology programs, such as the Integrative Physiology department here at CU Boulder. In addition to aligning with Vision and Change core concepts, the Phys-MAPS also incorporates common published student misconceptions (e.g. Peleaz et al., 2005; Guy, 2012) and aligns with the Core Principles of Physiology (Michael and McFarland 2011), a conceptual framework based specifically on the feedback of physiologists. Structurally, the Phys-MAPS assessment is composed of 12 physiological scenarios and 70 “likely/unlikely to be true” statements that require students to be able to recognize and apply aspects of the core concepts in generally novel contexts. Although the Bio-MAPS project is nearing its completion, there is currently funding that will support the completion, validation, and publication of the Phys-MAPS.

The third general step in backward design is to develop instructional activities that can help students meet the educational goals. A critical component of designing effective instruction is to recognize, address, and incorporate students’ prior knowledge and preconceptions into instructional practices. Without direct attention to the knowledge students have entering courses, students may not learn concepts correctly or revert to misconceptions after the instruction period (Bransford et al. 1999; Model et al. 2005). While some information about misconceptions and challenging concepts in physiology is available, published data on these issues are diffuse. As of now, there is no review that compiles what is known about physiology misconceptions and student thinking as they relate to core physiology concepts for either the Vision and Change framework or the Core Principles of Physiology framework. Thus, it is this component of backward design that this proposal will be addressing, by compiling and publishing a review of student thinking that is both aligned with these two conceptual frameworks as well as augmented with data we have gathered through the construction and validation of the Phys-MAPS assessment.

Through the process of constructing the Phys-MAPS assessment we are already collecting data on student challenges and misconceptions in two forms: 1) national, population level data on what students know at different points in a physiology program, and 2) interview data on student reasoning in the context of answering Phys-MAPS questions. For the first of these, Dr. Knight and I ran a national pilot of a previous version of the Phys-MAPS in Fall 2015. In the 2015 pilot, we gathered data from 2617 students from 14 universities. We are currently running a second national pilot of the final version of the Phys-MAPS, at 14 universities and in 24 courses at different time points in physiology majors/programs. From this 2016 pilot, we will have data on what students know coming into majors, what students appear to learn well during physiology programs, what misconceptions persist throughout a program, and what concepts on the Phys-MAPS are the most challenging for students to master. For the second source of data, we have already conducted 106 student interviews on general physiology problems and specific reasoning related to Phys-MAPS questions. Analysis of these data will allow us to better understand student challenges and why students have trouble with particular concepts. Between these two data sources, we have data that both support and extend the current understanding of student thinking in physiology.

For example, it has been previously documented that introductory biology students planning to go into elementary education hold misconceptions about the circulatory system, thinking that blood flows around the body before returning to the heart (Pelaez et al. 2005). As this misconception is on the Phys-MAPS, we have been able to extend our understanding of student thinking on this concept. We now have evidence that some students still hold this misconception as seniors in physiology majors, with only 68% of advanced students answering an item about this concept correctly. The Phys-MAPS assessment data are supported by interview data in which students discuss blood flowing through multiple organs before returning to the heart.

In another example, we have evidence of student thinking that has not yet been reported in the literature. One of the advantages of the Phys-MAPS multiple "likely/unlikely to be true" format is that we can see how students sometimes hold both correct and incorrect ideas simultaneously. We have both pilot data and interview data demonstrating that in the context of structure/function relationships of the cell membrane, students may know that proteins cannot cross cell membranes directly and why this is so, but still not fully understand how and when proteins can cross membranes. We believe we have many more examples of mixed student thinking, although a more thorough examination of the data will be required to elucidate these.

While some of this analysis of the pilot data and interviews will be included in the publication of the Phys-MAPS and covered under the current Bio-MAPS funding, there will be much more potential analysis of these data than time to complete for the initial Phys-MAPS publication. Specifically, we will not have the time or funding with which to fully capture the richness of the student interview data. To best analyze these data, we need additional time and independent raters to help code student thinking for different reasoning structures. This proposal addresses that by extending my salary for an additional semester and funding an undergraduate student to aid in the coding of the data. This will allow us to document and analyze these interview data and publish them alongside the Vision & Change and Core Principles of Physiology conceptual frameworks. While faculty that choose to use the Phys-MAPS will gain insight from student answers to the questions themselves, publishing the student reasoning associated with Phys-MAPS responses will provide a greater depth of information for faculty to use.

Study Design and Methodology

The goal of this proposal is to summarize student thinking on core physiology concepts across a physiology curriculum and provide suggestions of ways to address persistent student misconceptions. Most of the data used for this summary will have already been collected as part of the construction and validation of the Phys-MAPS assessment. These data will include between 2500 and 3000 student responses on the final version of the Phys-MAPS collected as part of a national pilot in 24 courses at 14 universities. I will also have data from 106 student interviews on previous and final versions of Phys-MAPS questions.

I will start summarizing student thinking by categorizing each of the 70 items on the Phys-MAPS into three different categories. The first category is information students understand coming into the physiology major after completing a general biology course. The second is information that students do not know well coming into a major but learn through the course of a major. The third category is misconceptions students continue to hold after completing physiology programs. The criteria for these categories will be determined after the pilot data has been collected. This will result in data that can be summarized in a table similar to Table 1.

Table 1. Example summary of student thinking reflected on Phys-MAPS assessment by Vision and Change Core Concepts. *Entry Knowledge*: Conceptual knowledge students have coming into physiology courses after general biology. *Acquired Knowledge*: Conceptual knowledge students do not come into physiology courses with but commonly acquire through a physiology program. *Persistent misconceptions*: Conceptual knowledge that students still hold after completing physiology programs. Phys-MAPS items within each category are represented by their question and statement number (e.g. Question B, Statement 1: B1).

	Information Flow	Energy & Matter	Systems	Structure / Function	Evolution
Entry Knowledge	e.g. B1, Z1, etc.				
Acquired Knowledge	e.g. G5, H1, etc.				
Persistent Difficulties	e.g. Z2				

We will further summarize student thinking on the pilot data by running an exploratory factor analysis to determine if there are suites of student responses that correlate with each other and may represent different stages of student understanding.

Although having student thinking reflected by the Phys-MAPS organized in this way will help elucidate what aspects of concepts students find most challenging to learn, knowing that students get questions wrong is only part of the information that can help guide the design of instruction. It is also important to know what students' alternative conceptions are, i.e. if students do not know the right answer, what are they thinking instead? To provide greater detail about how students think about questions when they are getting them wrong, I will analyze interview data using a grounded theory approach to establish a framework for coding student reasoning (Charmaz, 2000). Following the development of the codes, I will work have at least two raters code the interview data, starting with items associated with persistent student difficulties. These coded interview data will allow us to determine if there are common patterns of student thinking associated with incorrect answers on the Phys-MAPS. These patterns of student thinking will then be presented alongside the item level analysis.

This summary of student thinking across a major will then be published and available for faculty to both better understand student thinking and better use Phys-MAPS information to develop instructional activities aligned with the core concepts of physiology. In addition, I will also identify and/or develop instructional strategies for the most persistent student misconceptions. The first step will be to use resources such as Course Source, National Center for Case Study Teaching in Science, Advances in Physiology Education, Life Science Teaching Resource, and other teaching resource databanks to identify effective instructional techniques for the persistent misconceptions. If I cannot find documented effective techniques that address the misconceptions we identify, I work on developing new instructional strategies that could be broadly applicable in multiple types of physiology courses.

Benchmarks for Success
I expect that this work will result in the following insights:

- Summary of student thinking across a major regarding physiology concepts
- Newly documented prevalence of previously described misconceptions
- Newly described physiology misconceptions and persistent difficulties
- Suggestions for instructional activities to address the most persistent misconceptions

I expect that this work will lead to at least two publications:

- A review what we know about student thinking in physiology in relation to the Vision and Change and Core Principles of Physiology frameworks
- Suggestions for instructional strategies for the most persistent misconceptions

Contributions to CU STEM education and education research
The timing of the Phys-MAPS project and this proposal's review of student thinking in physiology majors are fortuitous on both an institutional and national scale. At the institutional level, CU's Integrative Physiology Department (IPHY) is currently actively engaged in curriculum development, alignment, and assessment, receiving funding and support through AAU and TRESTLE for their efforts. Given the active nature of IPHY faculty members looking into curriculum improvements, these data on student thinking and instructional suggestions will be useful resources. In addition, many of the IPHY faculty members have helped to advance the Phys-MAPS assessment by providing feedback on the Phys-MAPS, helping us recruit physiology students to interview, and helping us pilot the Phys-MAPS with over 1200 IPHY majors. If IPHY continues to use the Phys-MAPS assessment, the richness of the data analysis resulting from this proposal will strengthen future interpretation and application of the Phys-MAPS results.

The tools proposed here will also be useful for transforming courses and curricula nationally. Notably, Dr. Erica Wehrwein at Michigan State University has recently assembled a Physiology Majors Interest Group (PMIG) that has been convening at national meetings to discuss what physiology program curricula should be. Many of these members have helped us to pilot the Phys-MAPS and welcome both the new assessment and more detailed descriptions of student thinking on core physiology concepts aligned with the assessment.

Budget and Timeline
The Bio-MAPS project funding will expire in December 2016. To complete the goals outlined in this proposal, I am requesting funding for continuation of my half-time postdoctoral research associate salary for spring semester of 2017 ($8000).

I am also requesting $1500 stipend to support an undergraduate student to help with coding protocols during the Spring 2017 semester and $500 for any additional interviews that may be needed.

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