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Cultivating a Scientific Mind in Undergraduate Students: Redesign of an Introductory Anatomy and Physiology Laboratory

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Abstract

Teaching introductory anatomy and physiology (A&P) requires a careful balance of conveying core content while at the same time fostering a deep interest in the subject matter. This is especially true in the laboratory where students are expected to not only master experimental procedures but also connect what they learn in the laboratory to course content. Traditional laboratory courses often have students follow "cookbook" style procedures. While these lab activities expose students to specific techniques or equipment, they are often at the expense of a deeper understanding of the content. The core concepts of physiology were developed to allow students to engage with course content in ways that build an integrated, conceptual understanding applicable to multiple physiological topics. In this article we describe the redesign of an undergraduate A&P laboratory course structured around three core concepts: scientific reasoning, structure/function, and systems integration. These concepts provide a framework whereby students can more effectively transfer concepts from one system to another. The course was redesigned into a "flipped" format in which students are first exposed to content prior to lab and laboratory activities were restructured to be inquiry- and problem-based. The goal of these curricular changes was to shift the focus from mastery of technical skills and declarative knowledge towards fostering critical thinking and clinical reasoning skills. An approach to the laboratory that includes the interrelated functional importance of systems and structures can create an engaging class atmosphere and deepen student's interest in the complex world of physiologic function. https://doi.org/10.21692/haps.2024.009

Key words: laboratory redesign, flipped course design, scientific reasoning, structure/function, systems integration

Introduction

Introductory physiology courses are challenging not only for students but also for faculty. Students struggle with the integrative and conceptual nature of the subject matter and faculty are challenged to find the appropriate balance of conveying content while fostering a deep interest in the subject matter. Core concepts are comprehensive ideas that can provide a framework to help students master anatomy and physiology (A&P) in a way that moves the learner beyond memorization of facts to a deeper understanding of the connected nature of physiological systems. The core physiology concepts are a set of 14 topics, designed by physiology educators, that can be applied across all physiological systems. (Goodman, 2018; Michael & McFarland, 2020). These concepts, along with their conceptual frameworks, have been utilized for course design (Crosswhite & Anderson, 2020; Hull et al., 2017), program design and assessment (Michael & McFarland, 2020; Stanescu et al., 2020), and textbook organization (Amerman, 2021; Silverthorn, 2015). While there are a few instances of faculty members adopting core concepts in the classroom (Chirillo et al., 2021; Crosswhite & Anderson, 2020; Michael, 2021; Stanescu et al., 2020), there is a dearth of information for faculty interested in redesigning laboratory courses around the core concepts.

In this article we describe the redesign of an introductory laboratory course in A&P structured around three core concepts: scientific reasoning, structure/function relationships, and systems integration. These concepts are routinely used by physiologists to organize and assess information to make connections between physiological

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systems. We specifically chose these three core concepts as the framework for our course redesign as they allowed us to shift the educational goals from memorization of content and mastery of technical skills toward fostering higher-level cognitive and clinical reasoning skills (Goodman, 2018). For students to demonstrate mastery of physiology, they must be able to transfer knowledge from one context to another (Barnett & Ceci, 2002; Goodman, 2018; Michael & McFarland, 2020). Transfer can occur more effectively when courses are designed in such a way that students are able to recognize the relationships between concepts and they are given multiple opportunities to practice applying the core concepts (Barnett & Ceci, 2002). By repeatedly relating the course content back to the three core concepts, and by having students be active participants in the learning process, they can more readily apply their knowledge of those concepts to other systems (Goodman, 2018; Michael & McFarland, 2020).

The specific inclusion of these three concepts in the framework for our redesign in no way negates the importance of the other core concepts, nor does it preclude the inclusion of them in the classroom. The three core concepts were selected because they allowed us to design laboratory activities that incorporated multiple opportunities for students to (1) practice scientific reasoning skills, (2) emphasize how structure gives rise to and is related to function, and (3) demonstrate how multiple systems are functionally related (Michael & McFarland, 2020). Figure 1 illustrates the how the three core concepts were used as the lens through which the course was restructured. In this model, all laboratory activities revolve around inquiry- and/or problem-based learning in which students actively engage with the core concepts as a way to transfer acquired knowledge to multiple systems (Goodman, 2018; Michael, 2006).

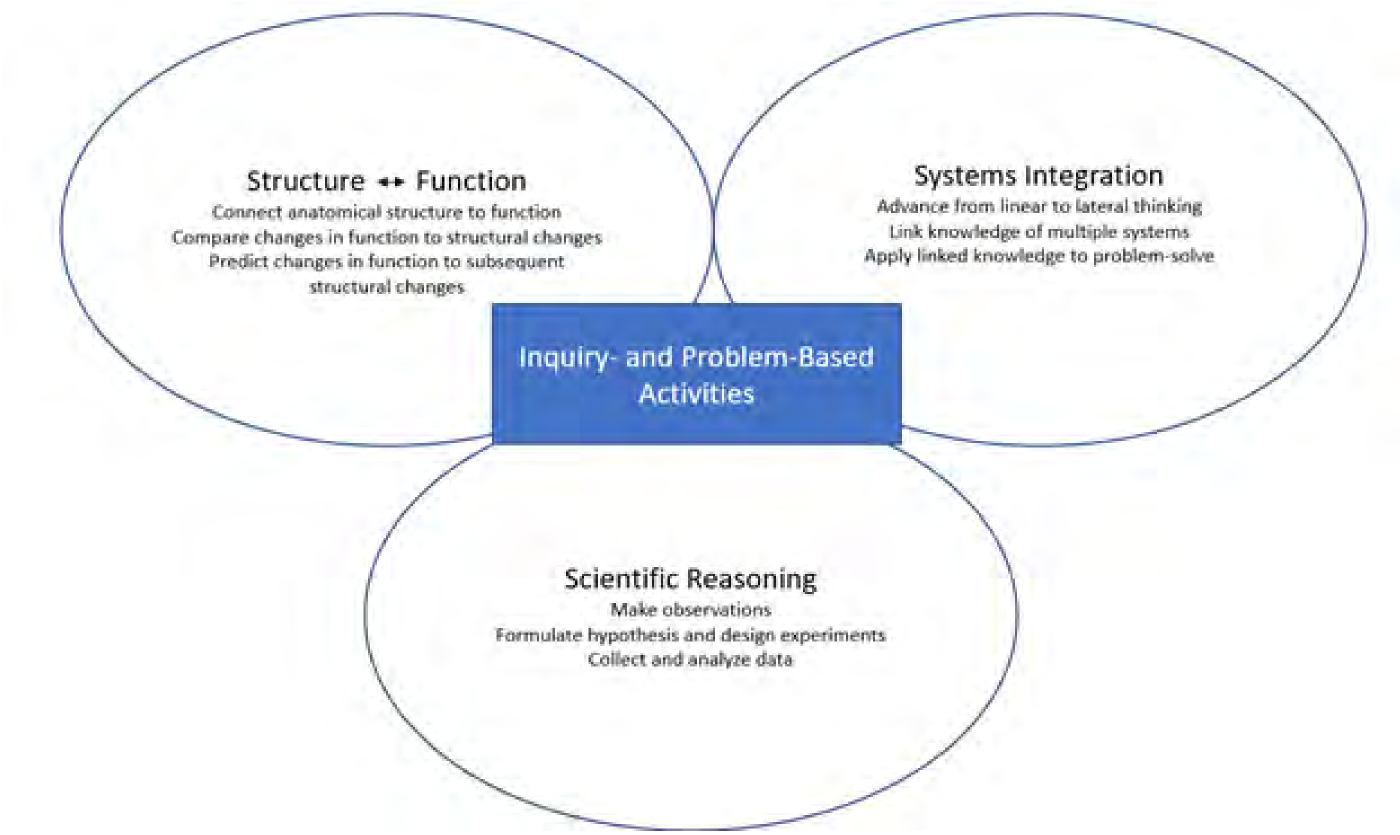

Figure 1. *Model depicting the framework used in the course redesign to an inquiry- and problem-based model centered around three of the core concepts of: structure/function, systems integration, and scientific reasoning.*

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Course Redesign

The A&P course described here is an introductory, two-semester course taught at a branch campus of a large state university. A&P is offered as two, three-credit lecture courses (A&P I and II) each linked to a one-credit laboratory course and enrolls a mixture of first- and second-year students majoring in allied health professions (nursing, occupational therapy, kinesiology) as well as upper-level students preparing for graduate school. Student backgrounds are quite diverse with some students having no prior science courses, and others having more extensive backgrounds. The course objectives (Table 1) are established by the university and are intended to be clear, concise statements of what learners will be able to demonstrate at the end of the course.

1. Develop and demonstrate a vocabulary of biological terminology to communicate information related to anatomy and physiology effectively.
2. Recognize and identify anatomical structures and evaluate physiological functions of each structure / organ system.
3. Recognize and explain the principle of homeostasis and the use of feedback loops to control physiological systems in the human body.
4. Recognize and explain the interrelationships within and between physiological systems of the human body.
5. Use anatomical knowledge to predict physiological consequences and use knowledge of function to explain the features of anatomical structures.
6. Apply knowledge of anatomy and physiology to real-world situations, including clinical cases, health and lifestyle decisions, and homeostatic imbalances.
7. Demonstrate laboratory procedures used to examine anatomical structures and evaluate physiological functions of each organ system.
8. Interpret and explain different types of anatomical images and graphs/ figures of physiological data.
9. Communicate clearly both verbally and in writing an understanding of the human body

Table 1. *Course Learning Objectives for Introductory Anatomy and Physiology.*

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Historically the introductory A&P lab courses at our campus were taught using a traditional one-system-at-a-time approach. Laboratory sessions were in person for four hours each week (2 hours, twice weekly) and students worked in groups of four. Students would receive a short lecture on relevant background and procedures and then would perform the lab activity following detailed step-by-step instructions. Rarely did students benefit from any prior exposure to the topic or content for the day. Once the lab activity was completed, students would analyze the data individually outside of class. Student understanding of anatomical structures and technical skills was assessed using practical exams, and physiological concepts were assessed through formal lab reports. While this course design exposed students to technical and, on occasion, clinical skills, students were not explicitly required to transfer what was learned from one week to the next or from one application to another (Michael & McFarland, 2020). Program assessment data indicated that while the traditional approach to lab was effective in teaching students an extensive vocabulary in A&P as well as recognizing and identifying anatomical structures, students were not adequately prepared to discuss the relationships between physiological systems, predict consequences of structure/function changes, or apply that knowledge to real world situations (unpublished data).

When we set out to redesign the laboratory course, our first goal was to utilize the three core concepts as a semester-long framework with which to organize learning activities. These concepts would be used as a conceptual framework with which to organize a hierarchy of smaller ideas to make up a concept (Michaels & MacFarland, 2020). Our second goal was to encourage critical thinking and clinical reasoning skills. Because most students enrolled in these courses enter a clinical setting following graduation it was imperative that our teaching methods reflect a consistent intent to foster clinical analytical skill. This goal was developed following the recommendations and practices discussed in Teaching Clinical Reasoning and Critical Thinking: From Cognitive Theory to Practical Application (Richards et al., 2020). Specific care was taken to encourage clinical and critical reasoning not just explicitly, but implicitly by modeling clinical reasoning and problem solving. Our third goal was to engage students in the learning process and make them responsible for their learning. The learning activities and classroom climate had to be such that conditions were favorable to learning. Our last goal was to demonstrate the relevance of physiological systems to everyday life.

To meet these goals, an inquiry- or problem-based approach was adopted. Studies examining the relationship between student learning and modes of teaching have repeatedly shown that active learning such as inquiry- and problem-based approaches, are more effective than lecture alone. (Alaagib et al., 2019; Alkhasawneh et al., 2008; Casotti et al., 2008; Richards et al., 2020) Although there has been a push in recent years towards inquiry-based learning, many physiology lab courses are still using the traditional approach (Frisch et al., 2018; Michael & McFarland, 2020; Rehorek, 2004). These conventional style labs do not necessarily provide an opportunity for students to develop their own understanding of physiology using scientific reasoning or to apply the content to their daily lives. By creating an environment that engages students in the scientific process, students can achieve more meaningful learning and they can apply their understanding to multiple systems simultaneously (Michael, 2006; Michael & McFarland, 2020). By giving students a conceptual framework that can be broadly applied, the new approach will continue to serve students in graduate and clinical settings where they must be motivated and able to critically assess information and analyze multiple organ systems and complex processes (National Research Council, 2000; Richards et al., 2020).

An inquiry- or problem-based approach to lab typically means reducing the body of knowledge to be acquired (Goodman, 2018). This approach allows the focus to be on core concepts rather than rote memorization of facts so that students are better able to understand how organ systems work together in a complex organism (Michael & McFarland, 2020; Stanescu et al., 2020). While each body system is covered in lecture, for lab we selected activities for those body systems that had clinically relevant topics that we thought would be of interest to students at the introductory level. Table 2 provides a summary of several of the redesigned labs and how the three core concepts were used for each body system. For example, when discussing digestive disorders, students are not only learning about the structure/function of the digestive system, but they are also learning that proper digestive system function impacts multiple body systems. When studying vision (or any of the special senses), incorporating a multisensory activity instead of simply focusing on anatomy allows students to gain a better appreciation for the integration of multiple sensory inputs and how they produce our perceptual reality (Dunbar & Shade, 2021). By discussing lumbar disc injuries students not only connect anatomical structure to function, but they also learn how changes in function can lead to subsequent structural changes.

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Body System	Revised Curriculum	Previous Curriculum
Digestive System	*Topic: Celiac Disease and Other Digestive Disorders* SR: Hypothesize how tissue damage to small intestine would lead to symptoms of celiac disease. Why did grain-based diets foster the emergence of celiac disease? SF: Model the anatomy of the digestive system using clay. Discuss how the unique structure of organs might dictate their function (example: how do villi increase surface area and what purpose would that serve?) SI: Discuss how tissue damage in celiac disease affects the function of other systems. Discuss the extraintestinal manifestations that are commonly seen. CO: 1, 2, 3, 4, 5, 6, 9	Digestive System Anatomy (Cat dissections) CO: 1, 2, 8
Nervous System	*Topic: Auditory and Visual Reaction Times* SR: Design your own experiment to challenge auditory or visual reaction time. SF: Discuss how structures like the cochlea and photoreceptor cells are designed for transduction. SI: Explain how visual and auditory stimulus are converted into electrical signals, which are processed in the central nervous system. Discuss how action potentials then produce muscle contraction and movement. CO: 1, 2, 4, 6, 8, 9	Basic Neuroanatomy (Cat dissections) Reflex and Reaction Time (Computer Simulations) CO: 1, 2, 7, 8
Musculoskeletal	*Topic: Lumbar Disc Herniation* SR: Hypothesize how lumbar disc degenerative changes or injury would lead to various symptoms. SF: Build clay models of muscles. Explain how disc changes create subsequent functional changes. SI: Discuss how degenerative changes/injuries to the disc impact the nervous system. Discuss active rehabilitative exercises that impact neuromuscular structures. CO:1, 2, 4, 6, 8, 9	Musculoskeletal anatomy (Cat dissections) CO: 1, 2, 8
Special Senses	*Topic: Crossmodal Perception* SR: Hypothesize the impact of vision and olfaction on taste perception, and the impact of vision on scent perception. SF: Examine similarities of transduction in vision, olfaction and gustation. SI: Demonstrate neural integration by studying how vision impacts taste perception, how olfaction impacts taste perception, and how vision impacts olfactory perception. CO: 1, 2, 3, 4, 8, 9	Basic anatomy of sense organs (Examination of plastic models) Basic clinical examination (Tuning forks, opthalmoscope, etc.) CO: 1, 2, 8

Table 2. *Body systems in the previous and revised curricula. SR = scientific reasoning, SF = structure function, SI = systems integration, CO = course objectives met.*

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In addition to an inquiry-based design, we also employed a flipped classroom model (Al-Samarraie et al., 2020). In a flipped design (also called hybrid design) students are first exposed to course content outside of the classroom, thereby allowing them to engage with the content on a deeper level (Abeysekera & Dawson, 2015; Al-Samarraie et al., 2020; Awidi & Paynter, 2019; Gilboy et al., 2015; Kang & Kim, 2021; Sadik & Abdulmonem, 2020). Face-to face time is spent on active learning with collaborative learning being an important part of the process (Abeysekera & Dawson, 2015). Courses in which students are asked to read and complete assignments before coming to class and have active collaborative activities have been shown to improve student learning. (Awidi & Paynter, 2019; Kang & Kim, 2021; Sadik & Abdulmonem, 2020).

Laboratory courses are an ideal place to incorporate a flipped design because the lab involves significant preparation by the student prior to in-class meetings. Face-to-face time can then focus on problem-based (Alaagib et al., 2019; Alkhasawneh et al., 2008; Richards et al., 2020) and active, multi-sensory learning activities (visual, auditory, read-write, kinesthetic) (Alkhasawneh et al., 2008; Baykan & Naçar, 2007; Breckler & Yu, 2011; Wagner, 2014) that are designed to effectively stimulate multiple learning styles.

Each lab module follows the basic flow chart illustrated in Figure 2. Students are first exposed to course content by engaging in e-learning activities. These activities, ranging from textbook readings to instructor created online videos, are designed to focus on the first level of Blooms taxonomy – or the *knowledge domain* (recall of basic facts, terms and basic concepts) (Krathwohl, 2002). Online pre-lab quizzes are used to assess basic competency with subject knowledge prior to face-to-face meetings. During face-to-face time, students work in small groups to engage in collaborative laboratory activities designed to focus on higher levels of Blooms taxonomy – *application, analysis, synthesis and evaluation* (Krathwohl, 2002). At the conclusion of each module student learning is assessed through group presentations, informal class discussions, or group quizzes. Group quizzes have been shown to be an effective tool to stimulate meaningful learning because they require students to articulate their understanding of the subject matter and to respond to challenges (Jensen et al., 2002; Michael, 2006; Slusser & Erickson, 2006).

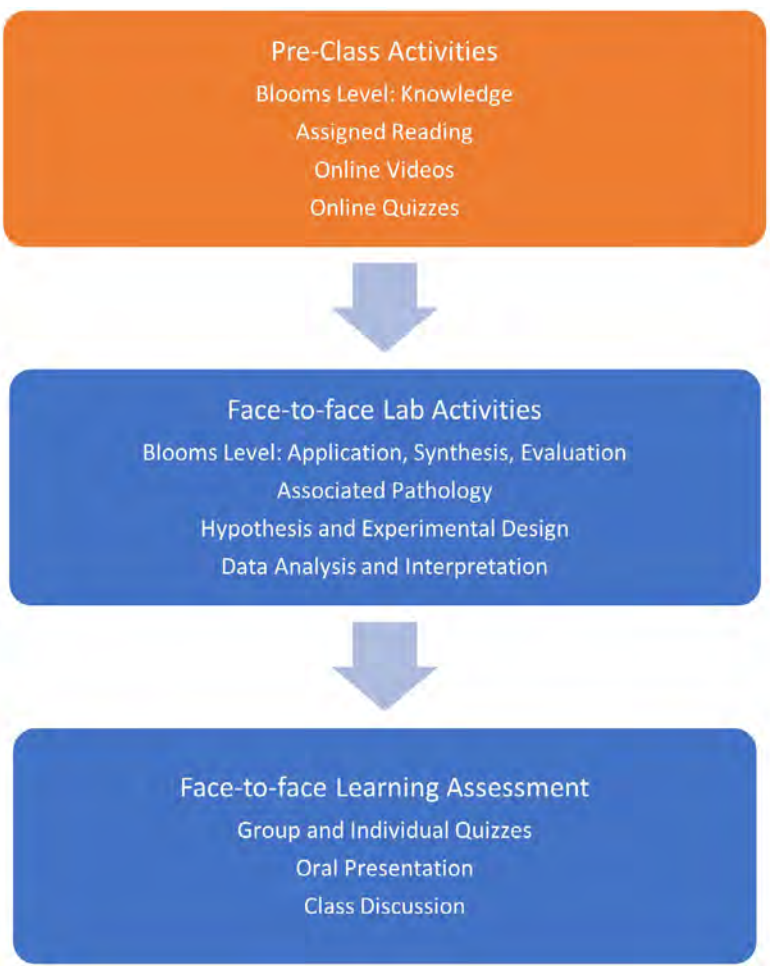

Figure 2. *Flow diagram illustrating the basic organization of each lab module.*

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Below, we provide a detailed example of a laboratory module that was redesigned around the three core concepts. We are hopeful that this framework will allow other instructors to tailor the content of their courses in such a way that students are given multiple opportunities to ask and answer questions (scientific reasoning), explore relevant connections between structure and function and solve problems that require the transfer of knowledge to multiple physiological systems.

Example of Course Redesign: Musculoskeletal System

Prior to the redesign, the musculoskeletal system lab utilized cat dissections to introduce students to the origin, insertion, innervation and action of muscles. Over the course of several weeks, students dissected preserved cat specimens and labeled pertinent structures. While the dissections allowed students to visualize the muscle tissue, the lab activities focused mainly on memorization of structures and relevant facts rather than the relationship between the structures and their functional relevance to other systems. In our experience, students were focused on making lists and finding pneumonic devices to memorize anatomic terms, but they failed to understand the relationships between the structures, or their relevance to other systems and, opportunities to hypothesize as a group were very limited.

When redesigning lab activities for the musculoskeletal system we wanted to create a learning environment that focused on open-ended questions relating content to the three core concepts. In the redesign, the spinal portion of the musculoskeletal system is studied over a two-week period. During the first week students focus on the structure/function of the musculoskeletal system by studying the origin, insertion, innervation, and actions of muscles. Prior to class, students are introduced to the musculoskeletal system through an online human cadaver dissection program. After completing the online activities, students take an online quiz that is designed for two purposes: (1) allow students more practice with the material and (2) assess their understanding of the content prior to the face-to-face lab. During lab, students work in small groups to build muscles with clay on small skeletons. Once the models are completed the students are quizzed as a group on the origin, insertion, innervation, and actions of the muscles, as well as the related osseous structures. Research has indicated the efficacy of utilizing anatomic representations of human structures when learning human anatomy, and that clay modeling effectively provides a kinesthetic and sensory method of learning that students subjectively prefer (DeHoff et al., 2011; Motoike et al., 2009). Group discussion is encouraged prior to answering each question so that disagreements can be adequately investigated. This step often leads to interactions where students must process their thoughts and articulate them to their peers, thereby either creating a greater level of confidence in their response or a realization that further study is needed.

During the second week of the spinal-musculoskeletal module, we expand the focus to include systems integration and more advanced scientific reasoning by studying lumbar disc degeneration and herniation. By utilizing a common pathology, we are able to pose a series of questions and develop possible answers, as students acquire new information that they can then relate back to content that was previously learned (Barnett & Ceci, 2002). Other reports have shown that this approach allows the focus to remain on causal relationships and improves the depth of understanding of the A&P being studied (Goodman, 2018).

Before coming to lab, students read a primary research article on lumbar disc injuries (Freeman et al., 2010). This article was selected because it can be understood by undergraduate students, and it provides an opportunity to integrate the three core concepts. For example, this paper introduces concepts such as deep stabilizing muscles and their functional importance (structure/function), why small muscles with a high cross-sectional area would function more as stabilizers rather than producers of motion (structure/function, scientific reasoning) and how afferent feedback subsequent to pain/injury might lead to reflex muscle inhibition and impede proper muscle activation (systems integration) (Freeman et al., 2010). By shifting the focus away from a simple model of disuse leading to weakness, and instead evaluating evidence suggesting that pain and neurologic dysfunction can lead to subsequent tissue changes, students are encouraged to utilize greater levels of critical thinking (Freeman et al., 2010). Additionally, students were given a PowerPoint presentation in which the stages of several progressive exercises were demonstrated for them, first on a stable base and then on a labile base. Students were required to work as a group and then bring to class their own example of a progressive exercise that they demonstrate or present to the class.

The face-to-face portion of this lab is divided into three parts: review of lumbar anatomy, introduction of imaging studies, and a learning activity involving rehabilitative exercises and stability balls. We begin the lab with a review of lumbar anatomy utilizing pictures from open educational resources as visual aids. In this portion of lab more in depth content related to lumbar discs is covered. Once students are introduced to greater complexity in structures, then open-ended questions can be explored that focus on function and pathology to stimulate critical thinking and clinical reasoning. In this process students are encouraged to view functional spinal units as a whole rather than as separate structures (Freeman et al., 2010).

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The questions in Table 3 are examples of the types of questions that can be asked in this portion of class. The questions posed during lab are dictated, in part, by student responses on any given day; therefore, not all questions will be asked in every class period. By asking questions, students can explore and discuss answers allowing them to practice their newly acquired knowledge of musculoskeletal anatomy and relate that knowledge to the pathology of lumbar disc injuries. Instructors demonstrate modeling of scientific reasoning by asking how/why questions to improve students critical thinking skills (Richards et al., 2020). This approach has been shown to improve the depth of understanding of the system being studied (Goodman, 2018). As questions are asked and answered throughout class, students are encouraged to focus on the relationship between the content and the three core concepts.

How does the basic composition and structure of the disc (the concentric lamella of the annulus fibrosus (AF) and the gelatinous nucleus pulposus (NP)) dictate its function? Why is the study of these structures and of lumbar disc herniation (LDH) important clinically? (SR, SF)
When viewing the neural foramen in relation to the disc or facets, can you visualize how any encroachment from nuclear material or osseous growths could create direct pressure on neural structures and resultant neurologic symptoms? What types of symptoms might be seen in this scenario? What types of pathophysiological mechanisms might be involved in pain generation? (SR, SF, SI) This is a straight-forward observation but a necessary step towards progression to understanding clinical symptoms that result from issues that do not involve direct mechanical compression.
Can you see why changes in the proteoglycan content of the nucleus might impact the hydrostatic pressure and therefore alter load distribution and mechanical forces? What about tears in the lamella of the annulus or end plate junction failures? With these types of degenerative changes what changes might be seen in that functional spinal unit over time? Why might a patient suffer a disc herniation even in the absence of any specific trauma? (SR, SF)
How might a reduction in blood supply to the disc change the integrity of the tissue over time? (SR, SF, SI)
If we continue this reasoning, as motion is limited, what changes might occur as the body attempts to stabilize the area? How would ankylosing of the motion segment impact the region above or below? (SR, SF)

Table 3. *Examples of questions that can be asked during the face-to-face lab activities and their relationship to the core concepts. (SR = scientific reasoning, SF = structure/function, SI = systems integration)*

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Once relevant structures are reviewed and located on the Open Education Resources visual aids, focus is shifted to transfer that knowledge to imaging studies in the second part of lab. Lumbar anatomy is reviewed on X-ray as well as in the midsagittal and axial planes on MRI. Many online resources are available to offer clear visual content of the lumbar region. One excellent reference which includes high quality visual imaging that demonstrate both normal anatomy and various pathologies can be found at: https://www.radiologymasterclass.co.uk/. This site includes a gallery section with examples of x-rays demonstrating various traumatic injuries as well as accurately labeled lumbar MRI studies of both normal anatomy and pathology. Images from the research paper that students studied prior to class (fatty infiltration into the multifidus muscles after injury) are also reviewed as a class. Sample questions and related content for this portion of the lab, and their connection to the core concepts, can be found in the supplemental materials.

In the third and final part of lab, utilizing knowledge that they gained earlier in the module, students explore and perform exercises to examine how these types of injuries might be rehabilitated. The exercises become increasingly more challenging by progressing from a stable to an unstable base, via the use of stability balls. Students demonstrate their own progressive exercises to the class and all students are given the opportunity to participate in the activity to their level of ability. Some students simply sit on the ball with a progressively narrower point of contact by moving their feet closer together while others complete more advanced exercises. These exercises allow students to be actively engaged in the learning process and provide an opportunity for students to practice scientific reasoning skills. Sample questions for this final part of lab, and their connection to the core concepts, can be found in Appendix 1.

Summary

In this article, we have described the redesign of our A&P laboratory courses from traditional labs to inquiry- and problem-based labs structured around three core concepts: structure/function, systems integration and scientific reasoning. By using these three concepts to create a framework to organize course content, we are able to shift the focus of the course from the mastery of technical skills to the development of higher-level cognitive skills. By creating a learning environment that challenges students to ask and answer complex questions, and by repeatedly relating the course content back to the three core concepts, students actively participate in processing new knowledge that they are then able to transfer to novel situations (Alaagib et al., 2019; Goodman, 2018). With this approach, instructors at other institutions should be able to focus the content of any lab around their specific areas of expertise while still utilizing the recommended format to focus on semester-long core concept themes.

An important aspect to the lab redesign was using a flipped course design. In traditional A&P courses, students are exposed to course content by listening to lectures and carrying out step-by-step procedures in lab. Students tackle the more difficult tasks of application of the material themselves through homework assignments or written lab reports. In a flipped course, students engage with the material outside of class so that they are prepared for an active, collaborative learning experience inside the classroom or lab (Gilboy et al., 2015). Without having first exposure to the basic content knowledge gained through pre-class activities, there would not be enough time during face-to-face lab meetings to focus on the higher levels of Blooms taxonomy. The example provided for the musculoskeletal lab illustrates the depth with which content can be covered, provided the students come to lab with a solid understanding of basic content (assessed via an online pre-lab quiz).

While we have not yet formally assessed student learning in the redesigned course, student comments have been positive. Students claimed that they enjoyed the engaging atmosphere of the labs and that they felt more motivated to learn the material. Since the redesign of the musculoskeletal module, several students have expressed an interest in careers in medical radiation technology and radiology while other students have incorporated stability ball exercises into their daily activities. While this is anecdotal, we are encouraged by the level of interest and engagement of students during the labs.

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Appendix 1. Sample laboratory questions and their connections to core concepts

Sample Questions	Related Core Concepts	Content Introduced by Exploring these Questions
How does the basic composition and structure of the disc (the concentric lamella of the annulus fibrosus (AF) and the gelatinous nucleus pulposus (NP)) dictate its function? Why is the study of these structures and of lumbar disc herniation (LDH) important clinically? *(Part 1 of Disc Pathology Lab)*	*Scientific Reasoning, Structure-Function*	The gelatinous NP has a high concentration of proteoglycans and therefore attracts and binds water. This is important to the discs mechanical/compressive properties and ability to exert pressure in all directions and manage compressive loads. Low back disc pain is a very common problem in the 20-50-year-old age group, as the disc undergoes extensive degenerative changes. It is a leading cause of pain and disability. The maintenance of spinal motion is critical to pain reduction as well as the preservation of normal lifestyle activities. (Errico, 2005; Priyadarshani et al., 2016)
When viewing the neural foramen in relation to the disc or facets, can you visualize how any encroachment from nuclear material or osseous growths could create direct pressure on neural structures and resultant neurologic symptoms? What types of symptoms might be seen in this scenario? What types of pathophysiological mechanisms might be involved in pain generation? *(Part 1 of Disc Pathology Lab)*	*Scientific Reasoning, Structure-Function, Systems Integration*	Pain can occur in the location of pathology, as most students would suspect, but symptoms may also occur at other sites and may have different pathophysiologic mechanisms. Students begin to see that pain may be generated not only by mechanical compression but also damage to nociceptive tissue from local degenerative changes as well as inflammatory mediators. Students can link symptoms that occur in other systems to LDH, such as a loss of bowel/bladder control. By following the scientific reasoning involved in central sensitization, students can see how sensory changes can occur as the result of processing issues, even in the absence of direct mechanical pressure. (Freynhagen & Baron, 2009)
Can you see why changes in the proteoglycan content of the nucleus might impact the hydrostatic pressure and therefore alter load distribution and mechanical forces? What about tears in the lamella of the annulus or end plate junction failures? With these types of degenerative changes what changes might be seen in that functional spinal unit over time? Why might a patient suffer a disc herniation even in the absence of any specific trauma? *(Part 1 of Disc Pathology Lab)*	*Scientific Reasoning, Structure-Function*	Over years, degenerative changes at the nucleus, annulus and end plates may occur with the development of scar tissue and mechanical changes. As subclinical failures occur a patient may suffer from LDH even in the absence of any trauma. This allows students to further contemplate avenues of treatment and rehabilitation that address biomechanical changes that are not readily visible. The concept of cumulative trauma injuries of the lumbar spine in the absence of any specific major event brings to the students awareness of the concept that pathology can arise from a slow cascade of events. This level of processing of information and the ability to connect lecture content to lab content, rather than memorization of unrelated facts more closely resembles clinical practice and the required reasoning. (Newell et al., 2019; Rajasekaran et al., 2013; Suri et al., 2010; Tavakoli et al., 2020)
How might a reduction in blood supply to the disc change the integrity of the tissue over time? *(Part 1 of Disc Pathology Lab)*	*Scientific Reasoning, Structure-Function, Systems Integration*	Disc tissue can begin to break down over time and may begin in the second decade of life. A reduction in blood supply occurs as early as the early 20's and results in the degradation of disc tissue. This content relates directly to the specific demographic that is frequently seen in college classrooms making the content relevant to the students. It also reminds students of the critical importance of proper blood supply to the health of all tissues. (Boos et al., 2002)
If we continue this reasoning, as motion is limited, what changes might occur as the body attempts to stabilize the area? How would ankylosing of the motion segment impact the region above or below? *(Part 1 of Disc Pathology Lab)*	*Scientific Reasoning, Structure-Function*	Disc height is lost, and vertebrae may lose their appropriate alignment to adjacent vertebrae. Anterior or posterior slippage can cause direct mechanical pressure (a different mechanism than they previously discussed) Osteophyte formation occurs as well and may result in fusion of the motion segment. This can lead to further changes at adjacent motion segments as they become hypermobile to compensate. This leads to further compensatory degenerative changes. An ability to follow scientific reason past the point of direct correlations is very important to the development of critical thinking. (Boos et al., 2002; Errico, 2005)

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What is the difference between muscle tissue loss from disuse and muscle tissue loss stemming from reflex inhibition of the muscle? Can you combine your knowledge of anatomy and physiology of spinal joints and muscles and your understanding of mechanoreceptors and transduction to give a possible mechanism of how we can see muscle control dysfunction, even if imaging studies do not show any obvious pathology? *(Part 2 of Disc Pathology Lab)*	*Scientific Reasoning, Structure-Function, Systems Integration*	Motor program changes occur due to pain and may remain altered even after pain resolves. Inhibition of the muscle leads to dysfunction and muscle tissue is replaced with fatty tissue. Cumulative trauma results in sub-failure injuries which damage soft tissues involved in transduction. This alters the feedback to the muscles and damages neuromuscular control leading to faulty muscle firing patterns and instability. This leads to further injury and inflammation in the area and the cycle continues. It is not necessary that students memorize this sequence. What is important is that they begin the process of critical thinking, connecting information from different systems and sources, and understanding that answers are not always straightforward. (Freeman et al., 2010; Panjabi, 2006)
How can changes seen in LDH lead to changes in sensory processing and alter proprioception? *(Part 2 of Disc Pathology Lab)*	*Scientific Reasoning, Structure-Function, Systems Integration*	Mechanoreceptor feedback of discs, ligaments and joints, through transduction, control muscle activity and reflexes. Degenerative changes that damage these tissues result in a loss of coordinated feedback, proprioceptive changes and instability. (Akuthota & Nadler, 2004; Izzo et al., 2013)
What other body systems might be involved in compensatory mechanisms that result from proprioceptive changes? *(Part 2 of Disc Pathology Lab)*	*Scientific reasoning, Structure-Function, Systems Integration*	Proprioception and the ability to accurately sense the position of body parts in space requires three bits of information: proprioceptive information, visual input and input from the vestibular system. This is an excellent example that encourages students to see multiple systems as a functional whole. Sensory and sensorimotor changes that impair proprioceptive function will lead to problems with gait and increase the likelihood of falls. Students can now combine all of this information to decide what other systems might provide compensatory mechanisms to stabilize the patient's gait. They can hypothesize how a stooped, shuffling gait might occur as a patient lowers their visual field to see the floor, widens the base of their stance for stability, and does not lift the foot fully off the ground (shuffling). They can even assess the importance of cognition in gait as elderly persons who perform cognitive tasks often stop walking, indicating an increased likelihood of falls. (Johnson et al., 2008; Pirker & Katzenschlager, 2017)
What types of exercises would be beneficial in these types of injuries and functional changes? *(Part 3 of Disc Pathology Lab)*	*Scientific reasoning, Structure-Function*	Muscle weakness as well as delays in proper muscle activation is seen in patients with low back pain and LDH. Core strengthening and improved motor control can help to maintain functional stability. Coactivation of multiple muscle groups and the use of an unstable base (like a stability ball) can improve balance and proprioception and lead to function improvement and stability. (Akuthota & Nadler, 2004; Behm et al., 2005)

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