DRAWING ON STUDENT KNOWLEDGE IN HUMAN ANATOMY AND PHYSIOLOGY

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MASTER OF SCIENCE

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ABSTRACT

Prior to instruction, students may have developed alternative conceptions about the mechanics behind human physiology. To help students re-shape these ideas into correct reasoning, the faulty characteristics reinforcing the alternative conceptions need to made explicit. This study used student-generated drawings to expose alternative conceptions Human Anatomy and Physiology students had prior to instruction on neuron physiology. Specifically, we investigated how students thought about neuron communication across a synapse (n=355) and how neuron activity can be modified (n=311). When asked to depict basic communication between two neurons, at least 80% of students demonstrated incorrect ideas about synaptic transmission. When targeting spatial and temporal summation, only eleven students (3.5%) were able to accurately depict at least one form of summation. In response to both drawing questions, student drawings revealed multiple alternative conceptions that resulted in a deeper analysis and characterization of the wide variation of student ideas.

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INTRODUCTION

Collegiate Human Anatomy and Physiology (HA&P) courses typically serve hundreds of students each semester, as it is required by a number of pre-professional programs. Because it is a prerequisite for numerous professional programs, the student population is diverse in terms of content knowledge and skills. Not only is HA&P a large and essential course for many students, it also has the reputation for being a difficult one, frequently serving as a “weeder” course for pre-professional programs.

Despite its large and diverse population, HA&P has not received a great deal of attention from discipline based education researchers, with the bulk of biology education research targeting introductory biology courses. Even though HA&P curriculum employs many of the skills and concepts covered in introductory biology, the deeply contextualized nature of this course poses new challenges to instructors and students, warranting individualized study. Due to the disparities between research efforts in HA&P and introductory biology courses, HA&P instruction is lagging. In order to help students succeed in this necessary course, it is important that the research community develops an informed understanding of the current state of undergraduate HA&P education from both the instructor and student perspective, beginning with the level of conceptual understanding students bring into the learning environment. In order to re-shape and broaden student understanding of HA&P, their initial thinking needs to be made apparent.

This study builds upon a small body of research centered in HA&P by investigating student understanding of neurons and neuron communication using student-generated drawings. Data analysis is framed using inductive analysis and five research questions were used to guide this study:

1. Will students draw neural concepts in Human Anatomy and Physiology?
2. How accurately do students draw neural anatomy?
3. How accurately do students draw neural physiology?
4. To what extent are students better at drawing neural anatomy than physiology?
5. What other alternative conceptions about neurophysiology do students articulate through their drawings?

Human Anatomy and Physiology Education Research

Students and instructors agree that HA&P is a challenging course requiring students to students to identify, understand, analyze, and predict structure-function relationships. In fact, self-reported survey data from students and instructors articulate some of the demands of HA&P that are most difficult for learners to meet (Michael, 2007; Sturges and Maurer, 2013). Specifically, students enrolled in HA&P must be able to:

- reason mechanistically
- reason about dynamic systems
- interpret graphs
- avoid teleological thinking

Structure-function relationships are at the core of HA&P, and evidence suggests that the "function" portion of these relationships (the physiological processes occurring in the human body) is one of the biggest learning hurdles for students to overcome (Michael, 2002; Michael et al., 2002; Carvalho, 2009). When thinking about the causality that drives structure and function relationships, it's not hard to see why students are able to demonstrate proficiency in anatomy-based concepts without mastering physiology-based concepts. Students can accurately recall a structure's name, description, location and general function without ever having to think about physiology correctly. As a result, proficiency in anatomy does not require one to build complex cognitive structures. However, students' understanding of physiology is reliant upon their anatomical knowledge, and their ability to build new knowledge structures, incorporating complex process and apply these knowledge structures to reason mechanistically. This process of reconstructing and applying new knowledge structures is far more cognitively demanding than simple recall tasks (Krathwohl, 2002).

In order to effectively teach students about HA&P, it's important to know how students think about this material before entering the classroom. Since HA&P pertains to how the human body functions, students do not enter a course as blank slates. They have first hand experiences with many of the concepts being covered and have had ample opportunity to develop a superficial understanding of physiologic events. For example, incoming students are familiar with exercise and some of its pronounced effects on cardiovascular activity, e.g. stronger heartbeats, yet they are often unable to accurately explain why apparent changes occur, e.g. the strength of the heartbeat increases because the tissues need more blood (Michael, 1998; Michael et al., 2002; Morton et al., 2008). Unfortunately, students' faulty reasoning about exercise is comparable to many of the ideas students bring into the classroom pertaining to physiology: they are scientifically inaccurate, resulting in alternative conceptions that students aren't readily willing to abandon (Smith et al., 1993; Macbeth, 2000).

Alternative conceptions[1] are difficult to address when explicit, but they are impossible to alter when they remain concealed within the learner (Posner et al., 1982). By making alternative conceptions apparent to the instructor, future instruction can be modified to target students' erroneous ideas and redirect students from their alternative conceptions to more accurate ways of thinking. In addition to alternative conceptions, it is possible that students are come to the classroom with little to no prior knowledge. It is unlikely that incoming HA&P students have well developed ideas about human physiology due to the microscopic, internal nature of the discipline. Therefore, it can be difficult to determine the appropriate knowledge level that future instruction should be built upon.

Much of the research done on both alternative conceptions and lack of conceptions in HA&P thus far has focused on the cardiovascular system (Table 1). This research provides valuable insight into how students think about cardiovascular anatomy and physiology, resulting in target instruction addressing those concepts evidenced to be exceptionally challenging. Instruments developed by Michael and colleagues (1998, 2002) provided the foundation for a series of investigations uncovering the knowledge undergraduates have about the cardiovascular system and how well they can use that knowledge to make physiological predictions. For example, after surveying a large population of HA&P students (n=1,052), of which 60% had received formal physiology instruction, 81% of students were unable to correctly predict change in arteriole resistance when presented with a change in cardiac resistance. As indicated through the literature presented in Table 1, HA&P instructors now have access to substantial

[1] To maintain consistency, "alternative conceptions" will be used to describe the scientifically inaccurate ideas students believe to be true.

data reflecting how HA&P students think about cardiovascular anatomy and physiology, and this data can be used to improve current HA&P curriculum

Table 1. Survey of literature identifying student difficulties in HA&P.

System	Author (Year)	Focus of Research	Data Source
Cardiovascular	Arnaudin and Mintzes (1985)	Structure, Function	Drawings, Interviews, Multiple-choice, Written responses
	Michael (1998)	Structure, Function	Multiple-choice, Written responses
	Michael et al. (2002)	Structure, Function	Multiple-choice, Written responses
	Pelaez et al. (2005)	Structure, Function	Drawings, Interviews, Written responses,
	Bahar et al. (2008)	Structure	Drawings
	Morton et al. (2008)	Structure, Function	Multiple-choice
	Mikkilä-Erdmann et al. (2012)	Structure	Drawings, Written responses
	Kurt et al. (2013)[a]	Structure, Function	Drawings, Free word association, Written responses
	Palizyan et al. (2013)	Structure, Function	Multiple-choice
Respiratory	Michael (1998)	Structure, Function	Multiple-choice, Written responses
	Michael et al. (1999)	Structure, Function	Multiple-choice
	Pelaez et al. (2005)	Structure, Function	Drawings, Interviews, Written responses
	Cliff (2006)	Structure, Function	Multiple-choice
Nervous	Ranaweera and Montplaisir (2010)	Structure	Drawings
Immune	Jones and Rua (2008)	Structure, Function	Drawings, Interviews
Musculoskeletal	Tunnicliffe and Reiss (1999)	Structure	Drawings
	Morton et al. (2008)	Structure, Function	Multiple-choice

Table 1. Survey of literature identifying student difficulties in HA&P (continued).

System	Author (Year)	Structure or Function	Data Source
Reproductive	Kurt et al. (2013)[d]	Structure, Function	Drawings, Free word association, Written responses
Endocrine	Patrick (2014)	Structure, Function	Drawings, Interviews
Digestive	Teixeira (2000)	Structure, Function	Drawings, Interviews
	Carvalho et al. (2007)	Structure	Drawings
	Rowlands (2004)	Structure, Function	Drawings, Interviews, Written responses
	Ormanci and Ören (2011)	Structure	Drawings, Multiple-choice, Written responses
	Patrick (2014)	Structure, Function	Drawings, Interviews
Urinary	Richardson and Speck (2004)	Function	Multiple-choice
Whole body	Reiss and Tunnicliffe (2001)	Structure	Drawings
	Prokop and Fancovicová (2006)	Structure, Function	Drawings, Written responses
	Ozsevgec (2007)	Structure	Drawings
	Bartoszeck et al. (2008)	Structure	Drawings
	Bartoszeck, et al. (2011)	Structure	Drawings
	Óskarsdóttir et al. (2011)	Structure	Drawings
	Dempster and Stears (2013)[a]	Structure	Drawings
	Dempster and Stears (2013)[b]	Structure	Drawings

In addition to the cardiovascular system, multiple researchers have investigated how students think about the body as a whole instead of focusing on individual tissues, organs, or systems (Reiss and Tunnicliffe, 2001; Prokop and Fancovicová, 2006; Ozsevgec, 2007; Bartoszeck et al., 2008, 2011; Óskarsdóttir et al., 2011; Dempster and Stears, 2013[a], 2013[b]). Studies of this nature can inform instruction at an organismal level. Prokop and Fančovičová (2006) used drawings and written responses to probe college freshmen to see if there was a correlation between the organs or organ systems they were capable of drawing and their knowledge about those organs/organ systems. Their results suggest that students had a relatively low concept of location for some systems (urinary, reproductive, and nervous) as indicated by absent or incorrect structures drawn. Conversely, analyses revealed significantly low performance in written work in response to digestive, respiratory, and endocrine questions, suggesting that what students know about location or structure is independent from their ideas about function. Prokop and Fančovičová also investigated what misconceptions first year students had about the human body. Results from the written questionnaire revealed that about 47% of the students (n=133) demonstrated poor understanding about heart physiology, suggesting the heart beating prolongs life.

Structure and Function

Structure-function (SF) relationships are ubiquitous across all levels of biology. Undergraduate biology curriculum overflows with examples of SF and these relationships should be a central concept in all levels of collegiate biology education (AAAS, 2011). Specifically, *Vision and Change in Undergraduate Biology Education* (AAAS, 2011) makes the call for all undergraduates to develop an understanding of how basic structural units dictate the functional capacity of all living things. Structure-function relationships are so crucial to biological literacy that Vision and Change identifies them as one of the five core concepts a student should have a basic understanding of before receiving an undergraduate degree. However, students have a hard time developing a meaningful understanding of how structure defines function making it difficult for students to recognize and rationalize these relationships (Michael, 2007; Sturges and Maurer, 2013).

In the context of HA&P, SF relationships can be described as the causal relationship between an object's physical structure or anatomy and their functional capability, i.e., their physiology. One could argue that SF relationships, either explicit or implicit, are at the core of HA&P curriculum since the conventional intent of instruction is to foster a meaningful understanding of the human body and how it functions (Silverthorn, 2013). As a result, students are expected to become proficient in both the identification and explanatory reasoning of SF relationships throughout the body. This expectation is not an arbitrary course goal created by an instructor; it is also the expectation of the multiple professional programs in which HA&P students seek to matriculate (HAPS, 2014). Traditionally, students take HA&P to prepare for future careers in fields (e.g. allied health sciences) that will require them to interact with the human body. Knowledge gained in HA&P courses is often the foundation that future instruction and training is built upon.

As previously mentioned, SF relationships are one of the most, if not the most, consequential concepts in HA&P, but they are generally the most the difficult for students to learn. Previous work has found that 1) students are able to identify and name anatomical structures but have trouble articulating the correlating function of those structures and 2) students can correctly make broad predictions about function but are unable to explain the mechanics underlying those predictions (Michael, 1998; Michael et al., 1999; Michael et al., 2002; Prokop and Fančovičová, 2006). In 1998, Michael surveyed 393 undergraduate students enrolled in life science courses to investigate their understanding of cardiovascular and respiratory physiology phenomenon. Michael used concepts elicited from his own teaching experiences that revealed alternative conceptions his students held. Specifically, students were asked to make predictions when presented with a physiology scenario and then explain the rationale for that prediction. Results showed multiple alternative conceptions in both components of student responses, the prediction and the explanation. In this particular study, the cardiovascular pump and the respiratory pump were the topics of most confusion. Michael and colleagues (1999) continued to investigate these student difficulties with a study using a new and much larger population of students enrolled in a physiology course (approximately 700 students) across seven different institutions using four alternative conceptions exclusively centered on respiratory physiology (See Appendix A for description):

1) “V_T/f misconception” - Tidal volume (V_T) and breathing frequency (f) as determinants of minute ventilation.

2) “Sa/PO_2 misconception” - The relationship between hemoglobin saturation (Sa) and partial pressure of oxygen in arterial blood (PO_2).

3) “O_2/CO_2 misconception” - O_2 and CO_2 exchange in the lungs

4) “met/vet misconception” - The relationship between metabolism and ventilation.

These results indicated that all four alternative conceptions were present to differing extent in the student population, ranging from 32-89% of the 393 student responses. Collectively across the four “alternative conceptions”, results indicated that students have a hard time explaining how oxygen and carbon dioxide are transported in the blood and the role of hemoglobin. Students also demonstrated difficultly with explaining the physical forces that drive respiration as well as the correlation of respiration and metabolic need.

A follow-up study done in 2002 (Michael et al.) reinforced that documented cardiovascular difficulties are persistent in multiple student populations across 12 institutions ranging from community colleges to research institutions. Michael and colleagues surveyed approximately 1100 students at eight different universities with a larger study targeting 13 student alternative conceptions pertaining to cardiovascular function previously exposed by Michael in 1998 (see Appendix A). These alternative conceptions can be summarized as blood hemodynamics, resistance, and regulation of cardiovascular activity.

In all of the studies mentioned previously, students demonstrated poor performance in functional concepts, not anatomical. When students are asked to do anatomical tasks (i.e., list or draw structures) they are able to provide evidence to suggest a moderate level of understanding (Patrick and Tunnicliffe, 2010; Kurt et al., 2013a). When asked to complete tasks requiring physiology proficiency (i.e., make predictions about homeostatic responses) student data suggest a much lower level of understanding (Michael et al., 1999, 2002; Kurt et al., 2013a). Collectively, the series of studies executed by Michael and colleagues (1998, 1999, 2002) provide strong evidence for the presence of alternative conceptions in HA&P content, specifically in cardiovascular and respiratory physiology, supporting the idea that physiology is more difficult for HA&P students than anatomy.

Instructors are aware that students have a hard time learning about the mechanisms that drive physiological phenomena discussed in HA&P and often place blame on circumstantial characteristics of the discipline and student population instead of the instructional approach (e.g., physiology requires students to think in terms of cause and effect, incoming students have low mathematical or graphical abilities; Michael, 2007). In 2007, Michael surveyed a cohort of 63 physiology instructors and the results indicated that instructors agree that instruction was not a major cause of the issues students have with learning physiology. The complex nature of the disciple and students limited prior knowledge seen as far greater issues in the eyes of the instructors. It is interesting to note that when the same survey was given to students currently enrolled in HA&P courses, they expressed similar rationale for why physiology was so difficult to learn, namely, the nature of the discipline and student prior knowledge factors being more influential than instruction (Sturges and Maurer, 2013; Table 2; Complete ranking in Appendix B).

Table 2. Selected comparison of instructor and student ranking of barriers to learning physiology.

Instructor Ranking Michael (2007)	**Student Ranking** Sturges and Maurer (2013)	**Survey item**
1	2	Understanding physiology requires the ability to reason casually. (Adapted in Sturges and Maurer – Understanding anatomy and physiology requires the ability to think in terms of cause and effect.)
3	3	Understanding physiology requires at least some limited ability to think about dynamic systems.
5	5	Physiological phenomena need to be understood at a number of different organizational levels simultaneously. (Adapted in Sturges and Maurer – Physiological phenomena need to be understood at a number of different organizational levels at the same time.)
8	11	Understanding physiology is based on an understanding of physics and chemistry.

HA&P is a discipline that incorporates principles of other content areas to explain and predict functional phenomena. Students have a hard time transferring prior knowledge gained in other relevant courses (chemistry, math and physics, in this case) to new contexts like HA&P (National Research

Council, 2000). Not only do students lack transfer skills, they also enter the classroom with subpar prerequisite knowledge, making the act of transfer even more challenging (Rovick et al., 1999). With faulty foundations in neighboring sciences and an inability to apply that knowledge, it's no wonder that students have a hard time learning and explaining physiological concepts.

As demonstrated in Table 1, previous work has primarily focused on either assessing structural content exclusively, or assessing student thinking on structural and functional concepts. For example, Ormanci and Ören (2011) assessed student knowledge of the digestive system by analyzing the structural characteristics of student-generated drawings. In this study, student knowledge was gauged by classifying drawings based on structural features, i.e. placement of organs and shape of organs depicted. Studies of this nature were assessing how well a student could represent, recall, or explain the structural features of a tissue, organ, or system.

Some previous studies have exposed student thinking at a functional level. These studies typically ask students to put forth knowledge the functional role of that tissue, organ, or system in regards to overall body function. For example, these studies often asked students to make predictions about a physiological response based on a given condition. For example, Morton and colleagues (2008) used this approach, facilitated through a multiple-choice assessment, to elicit student thinking about the effects of exercise on the cardiovascular system.

Note that of the literature presented in Table 1, only one of the 34 studies (Richardson and Speck, 2004) assessed student thinking about functional concepts only. This is not what one would expect to see when survey HA&P literature, speaking to the causal nature of SF relationships. Much like a conceptual understanding of physiology requires anatomical knowledge, an assessment measuring a physiological knowledge will most likely also (explicitly or inexplicitly) assess structural knowledge.

Use of Student Drawing

In order to expose alternative conceptions, assessments need to elicit student thinking without biasing student responses. Multiple-choice or matching items require students to select the answer option that best aligns with their own reasoning. Multiple-choice assessments have multiple shortcomings in both a conceptual and logistical sense, they confine student responses to a small number of options, they encourage guessing, and they mask any alternative conceptions an instructor might not be familiar with.

Short answer and written response formats are versions of free response assessments, which require students to provide their own reasoning instead of selecting an answer that best fits their understanding. Student-generated drawings are a type of free response assessment that can require students to generate an answer on their own instead of selecting an answer that best reflects their reasoning. Drawings and other free response items are a highly underutilized assessment format that can yield rich, valuable data about how students think and bring to light student ideas that are often extremely hard to predict (Köse, 2008; Cardak, 2009[a]).

By relying on students to provide all essential information necessary to correctly answer a question, the end product is more reflective of their own ideas instead of the instructor-generated options they may have been predicted to have. As a result, instructors are left with a more accurate idea of what students are thinking and can then move forward with more informed instruction, targeting documented alternative conceptions instead of incorrect ideas the instructor predicted they might have.

Drawing tasks can be helpful in eliciting a student's content knowledge, especially when the extent of that knowledge can vary tremendously (İlkörücü-Göçmençelebi and Tapan, 2010). Some of the previous work done using drawings asked students questions pertaining to their own awareness about internal body structures (Tunnicliffe and Reiss, 1999; Reiss and Tunnicliffe, 2001, Reiss et al., 2002). Specifically, students were asked to draw "what they thought" was inside themselves or other animals, sometimes with the focus on a specific body system. These questions were open-ended and resulted in drawings containing isolated organs and incomplete systems, demonstrating an inability in the students to recognize the relationships within and across organ systems.

When drawing questions are focused on a specific concept, the results can uncover specific and detailed student difficulties. For example, Ranaweera and Montplaisir (2010) used drawings to identify areas where HA&P students struggled in the context of neural tissue. This study took place in a lab setting, and students were asked to draw before and after receiving formal instruction. These drawings were then used to gauge how student thinking changed throughout the semester. Analysis of these student-generated drawings revealed multiple alternative conceptions that would have been difficult to tease out with a more rigid assessment format (i.e., multiple-choice or matching). Specifically, drawings revealed multiple student difficulties with neuron anatomy and reflex arcs, two very crucial concepts to neurophysiology.

Drawings have also been used to uncover unique and sometimes unpredictable ideas in settings outside of animal physiology. Student understanding of concepts like water cycles and river basins (Dove et al., 1999), photosynthesis (Köse, 2008), and Newton's Laws of Motion (Kara, 2007) have also been extracted through student drawings, revealing any alternative conceptions students may be harboring. Previously mentioned work demonstrates that stand alone drawings can be used to gather quality information about student thinking, but they can also be collected in conjunction with other data streams. Cinici (2013) used student-generated drawings and open-ended, free response written questions to elicit high school students' ideas about the life cycle and life forms of a butterfly. Analysis of both forms of data revealed that many of the inaccurate ideas students conveyed in their written responses were also present in their drawings. Kurt and colleagues (2013[a]) used a similar approach, the draw-write technique, as well as a free word association test to uncover how biology student teachers think about blood. Again, student-generated drawings exposed specific, incorrect ideas about blood.

In the last five years, there has been a dramatic increase in the research using student-generated drawings, and as a result, student-generated drawings have been used to collect student data across multiple disciplines (Table 3). Within these studies, drawings have been used to expose student thinking across a range of content platforms, from representing the chemical structure of naphthalene at the molecular level (Özden, 2009) to illustrating metamorphosis of a caterpillar into a butterfly at the organismal level. This versatility advocates for drawings as reputable means of data collection.

Table 3. Recent literature demonstrating the use of student-generated drawings across the sciences.

Content Area	References
Human Anatomy and Physiology	Kurt et al. (2013[a])
	Kiliç (2013)
	Ormanci and Ören (2011)
	Ranaweera and Montplaisir 2010)
	Patrick and Tunnicliffe (2010)
Organismal Biology	Cinici (2013)
	Kurt et al. (2013[b])
	Kurt et al. (2013d)
	Villarroel and Infante (2013)
	Topsakal and Oversby (2011)
	Cardak (2009b)
Small Biology	Kurt et al. (2013[c])
	Topsakal and Oversby (2012)
	Dikmenli (2010)
	Özden (2009)
Other	Subramaniam (2013)
	Yilmaz and Yardim (2013)
	Badrian et al. (2011)

Reveling Student Thinking in Human Anatomy and Physiology

The National Research Council (2000) suggested three main roles for assessment: monitor progress, provide feedback and enable accountability. Traditionally, these roles are met through multiple-choice or essay formats. Drawings can serve as an assessment item in the classroom since they have the potential to reveal progress, provide visual feedback to both the instructor and student, and result in student accountability for their learning (Tunnicliffe and Reiss, 1999; Reiss and Tunnicliffe, 2001; Van Meter and Garner, 2005). Previous work has collected student drawings in conjunction with interviews

(Dove et al., 1999) and open-response items (Cinici, 2013) and found consistency in the content and accuracy among students across data streams, suggesting student-generated drawings are reflective of what students think, making them a viable option for student assessment.

In some applications, drawings can result in a rich, more accurate reflection of what students are thinking than a traditional assessment platform. Drawings ask students to provide answers without the support of contextual clues, like those found in answer options for multiple-choice questions (İlkörücü-Göçmençelebi and Tapan, 2010). When students are assessed through traditional multiple-choice formats, they are selecting their answer from a group of possible choices that have been provided to them. In most cases, their answer must fall within one of the five options presented and if it does not, students may indicate a response that is not reflective of what they really think. When drawing, students do not feel the need to conform their individual and potentially unique response when being assessed through drawings, since there is nothing to conform to, unlike the traditional multiple-choice format.

In addition, traditional multiple-choice formats are much more conducive to camouflaging student difficulties by guessing. Students are taught in K12 schooling that in most cases, it is in their best interest to select an answer for every multiple-choice question, even if it means they are just guessing. As a result, student performance on a multiple-choice assessment is not always reflective of what they really think. Drawing assessments require students to generate their own answers, meaning they can not hide their lack of understanding by selecting an option that is already provided for them, resulting in a more genuine student response.

As depicted in Table 1, discipline based education research utilizes a number of different assessment formats to reveal student reasoning. Assessments are not universally effective at uncovering student reasoning, and a number of factors must be considered to determine which format will yield the most meaningful results under situational constrains. Well-conducted interviews provide researchers with copious amounts of personalized data but are often very time consuming to conduct and analyze. Multiple-choice assessments differ greatly from interviews in that they are relatively quick to administer and analyze but typically confine individuals to select from a set number of responses, potentially camouflaging an individual’s reasoning. Open-response formats contain features similar to interviews, typically requiring a student to provide explanation instead of simply recalling facts, as is often the case in multiple-choice assessments. However, like interviews, open-response data is individualized, typically requiring a more thorough and lengthy analysis than multiple-choice data (Wiggins and McTighe, 2005).

Assessment Revealing Teleological Thinking

When Sturges and Maurer (2013) asked students why HA&P is so difficult, they identified the causal-like nature of the discipline as being the most challenging part of the course, that is, the tendency of HA&P content to be thought about in terms of it's purpose. In other words, these students reported that teleological tendencies are the biggest obstacle to overcome when learning about HA&P. Teleological thinking refers to an explanation or type of reasoning in which the end goal or purpose of the phenomenon is at the forefront, determining the nature of the phenomenon (Mayr, 1961; Southerland et al., 2001). Teleological thinking is often recognized as one of the major barriers to overcome in evolution education (Alters and Nelson, 2002), but as reported by Sturges and Maurer (2013), it is also evidenced as a major hurdle in HA&P. Michael and colleagues documented examples of students using teleological reasoning within the context of the respiratory (1999) and cardiovascular (2002) physiology through a multiple-choice instrument. For example, when asked how respiration will change in response to an increased metabolism, students selected answers providing incorrect, teleological explanations (Michael et al., 1999; Figure 1). Data suggests that in this study, students were using reasoning that explained that changes in respiration were driven by the body's *need* for resources. Similar responses were observed within the context of the cardiovascular system when students were asked to predict arteriole resistance in response to an increase in cardiac output and again, students selected answers suggesting goal-oriented, teleological reasoning (Michael et al., 2002).

Michael et al. (1999)

"Respiration decreases because the body doesn't need as much oxygen since anaerobic metabolism can occur in the absence of oxygen."

"Respiration is unchanged because an increase in respiration is not needed for metabolism to increase."

"Respiration is unchanged because the body's need for oxygen is determined by metabolism not respiration."

Michael et al. (200):

"Resistance will decrease because more blood needs to be returned to the heart."

"Resistance will decrease because more blood needs to flow through the vessels."

Figure 1. Examples of teleological reasoning selected through multiple-choice items.

The instruments used by Michael and colleagues in 1999 and 2002 provide substantial evidence that students are using teleological thinking in HA&P but the format of these instruments limits the utility of this data. As stated previously, when students are being assessed in a multiple-choice format, their true thinking can be masked by provided conditions. Free response items eliciting evidence of teleological thinking, like those gathered in Figure 1, would afford researchers and instructors with a more accurate view of how students are thinking about HA&P phenomenon from this goal-oriented standpoint. For this study, we chose not to constrain student responses through a multiple-choice format, instead, we used drawings, a type of free response, to reveal any potential evidence of teleological thinking.

Assessment Revealing P-prims

Within the physics education research community, emphasis has been directed to uncovering epistemological resources, that is, the ways in which a student comes to know or gain knowledge (Elby and Hammer, 2010). Identifying the ways in which student answers differ from an expert is meaningful in it's own right, but by developing a better understanding about how students build their own knowledge constructs, we, as a community of educators and researchers, will be more capable of promoting beneficial, epistemological change and improve teaching and learning in higher education (Hutchison and Hammer, 2009). Physics research has extensively explored student thinking in depth across the disciple yielding meaningful evidence pertaining to student reasoning and problem solving (Hofer and Pintrich, 2004). As a result of this research, the framework of “p-prims” has surfaced as a way to explain how students develop an epistemic construct to justify the physical world (Hammer et al., 2002).

Phenomenological primitives, or p-prims, were first introduced by diSessa (1988,1993) to describe the intuitive ideas students’ have internalized that attempt to explain the physical phenomenon they have personally experienced. P-prims are relatively simple constructs that attempt to justify the mechanics of an event and require little to no explanation. Originating out of physics, diSessa (1988, 1993) and Hammer (1996) use p-prims to combat what was traditionally known as alternative conceptions or misconceptions. Instead of erroneous answers being attributed to well-developed, stored constructs (alternative conceptions), diSessa and Hammer suggest that students are readily and subconsciously applying pre-existing bits of intuitive knowledge (p-prims) to new contexts, attempting to rationalize the mechanics of the newly encountered phenomena.

One of the most well cited p-prims explains how students may think about proximity and intensity, coined *Closer means stronger*. Applications of the *Closer means stronger* p-prim could be as follows: music is louder the closer you are to the speaker; fire feels hotter the closer you are to the flame; the closer you are to a light, the brighter it appears. Students may abstract knowledge gained from an original experience(s) and formulate a generalized explanation (p-prim) that can be applied to other phenomena involving proximity and intensity, such as seasonality. Students may be using the *Closer means stronger* p-prim to generate the idea that it is hotter in the summertime because the earth is closer to the sun (Hammer, 1996).

In addition to exposing the nuances of student thinking, it’s valuable to explore contextual effects on the construction of epistemologies. As introduced by Southerland and colleagues (2001), pre-existing p-prims may be at work in fields outside of physics, informing how students think about physiology and guiding them to a more conscious, teleological rational. Students’ p-prims may be defining the “*need*” of physiology leading to teleological thinking; that is, students may be using their intuitive knowledge about real-world physical events, not necessarily content-related, to frame how they think structures need to interact to allow for their p-prims or “rules” to function.

Because p-prims rarely take on prepositional form, their presence is easily masked by the contextual components of a response (diSessa, 1993). From a student’s perspective, p-prims don’t require an explanation about the mechanism of action. Reasoning with p-prims works because “that’s just how it is”. Because of their ambiguity, multiple-choice survey items are not a suitable format for exposing the presence of p-prims. Even if a student selects an incorrect answer on a multiple-choice assessment, the item alone is not a sufficient amount of evidence to suggest the presence of a p-prim. An incorrect statement is not a p-prim; the intuitive reasoning a student uses to rationalize that statement is the p-prim. In order to make reasonable claims regarding the likelihood of a p-prim influencing a statement, one needs to collect evidence elucidating the internalized process a student uses to select a statement.

Physics education researchers have primarily used interviews when investigating p-prims and conceptual reasoning because of the rich, genuine data they produce. However, interviews are a lengthy process, requiring a significant amount of time to collect each individual data point. Human anatomy and physiology courses are often very large courses and conducting 300-400 interviews to capture student thinking at one point in instruction is an incredibly difficult feat.

Instead of attempting hundreds of interviews, this study used a form of free response items to expose student thinking, student-generated drawings. To our knowledge, student-generated drawings have never been used to elicit possible p-prims with a large student population, regardless of the discipline. Because drawing requires students to self-select the appropriate information and incorporate it correctly, drawings may serve as a useful tool in exposing highly internalized reasoning such as p-prims as well as a more manageable assessment format for large courses.

Drawing in HA&P

By relying on students to provide all essential information necessary to correctly answer a question, the end product is more reflective of their own ideas instead of the instructor-generated options they may have been predicted to have. As a result, are left with a more accurate idea of what students are thinking and can then move forward with more informed instruction, targeting documented alternative conceptions instead of incorrect ideas the instructor predicted they might have.

In this study, we wanted to explore student thinking without biasing them with an instrument like a multiple-choice assessment, therefore, we use open-response drawing prompts to explore how students think about SF relationships. While we knew students might be struggling with things like teleological thinking or p-prims, we thought it was important for those types of reasoning to become evidenced without a targeted distracter, resulting in more versatile findings. Because of these reasons and those discussed in previous sections, we felt drawings would serve as an effective format to elicit student thinking in HA&P.

METHODS

Course Context

This study took place in the first semester of a two-course sequence of HA&P offered at a large, public, Midwestern university. High enrollment required the first course of the series to be offered in two sections both taught by the same instructor and graduate teaching assistant. The HA&P sequence is a prerequisite required by numerous professional programs (e.g., clinical laboratory sciences, nursing, pharmacy, radiological sciences, respiratory care) and can be used to satisfy the general sciences education requirement of all undergraduates attending this university. As a result, the student population for the Fall 2012 semester was comprised of a diverse student body (Table 4) at various stages of their academic careers (Table 5).

Table 4. Student population by major.

Majors	No. of Students	Percent (%) of Course Population
Nursing	118	22.7
Health and Wellness	112	21.6
Pharmacy	106	20.4
Allied Sciences	78	15.0
Life Sciences + Other STEM	54	10.4
Other	51	9.8

Table 5. Student population by class.

Class	No. of Students	Percent (%) of Population
Freshman	138	26.6
Sophomore	246	47.4
Junior	67	12.9
Senior	68	13.1

Instruction

The course was taught primarily using traditional lecture that included the addition of occasional small-group and whole-class discussions. The auditorium housed two large projectors: one was primarily used by the course instructor to display pertinent images from the course textbook while the second projector was used by the graduate teaching assistant to simultaneously diagram course content. The graduate teaching assistant was involved in every lecture annotating the lecture drawings. These diagrams were cooperatively developed by the graduate teaching assistant and course instructor prior to class and were often abstract representations of body systems and modified box-and-arrow models that were designed to illustrate structural organization or complex physiological processes (Appendix C). Student achievement in both courses was evaluated through individual performance on summative multiple-choice exams, short writing assignments completed in class, formative online quizzes and online Learnsmart modules comprised of knowledge level question designed to assess factual recall (for more information on course assessment, see Appendix D). In order to facilitate this research, students were also asked to generated drawings as a form of formative assessment. These drawings were not graded and were completed on a voluntary basis. Students were assigned specific readings out of the textbook (Saladin, 2012), but there were no reading checks or quizzes to verify they had completed the readings before class.

The HA&P course began with an introduction to the chemical properties and cellular structures necessary to understand human anatomy and physiology. The later portion of the course was centered on body organization, form and function relationships and homeostatic regulation from the chemical to the system level for the integumentary, musculoskeletal and nervous systems.

Data Streams

Two drawing tasks (Table 6), written by the research team in accordance with the course instructor and predetermined course learning goals, were the focus of this research. These drawing tasks were presented via two large projection screens in the front of the classroom, making them visible to all students present in class

Table 6. Drawing tasks used to elicit student thinking.

Drawing	Focus	Drawing Task
1	Neural Anatomy	Draw a diagram of 2 typical neurons in a linear pathway. Label the significant regions. Using arrows, show the direction of information flow along the neurons.
2	Neural Anatomy + Neural Physiology	Draw a neuron and illustrate how signals arriving at the receiving end could be varied in strength and complexity. On the same neuron, illustrate how signals could be varied in strength and complexity at the output end.

Drawing Task 1 was presented to students prior to any formal, in-class discussion about neurons or the nervous system; however, students may have been introduced to pertinent material through textbook reading assignments. Students had access to reading assignments at the beginning of each chapter and were instructed to come to lecture having already read sections of the textbook that would be covered in class that day. If students read the appropriate sections prior to coming to class, they would have been introduced to enough content to accurately answer both drawing tasks, but as mentioned previously, there were no reading assessments used, so we are unable to determine if students had read about neural anatomy and physiology before they were asked to draw these concepts in class.

Drawing Task 2 was presented to students after they received formal instruction about neuron structure and basic synapse physiology. More specifically, instruction between Drawing Task 1 and Drawing Task 2 covered neuron anatomy, the role of ions and membrane potentials, graded potentials, action potentials, and basic synapse transmission. Instruction was lecture based and utilized instructor-generated drawings as well as figures from the required textbook (Saladin, 2012). Additional information regarding instruction can be found in Appendix (See Appendix E).

Both questions were presented at the same point in instruction across both sections of the course as to reduce any section bias. After approximately 5-8 minutes, the course instructor would end the activity and collect the drawings. There were no course points associated with the participation or completion of these drawings and each student had full ability to choose not to participate without any detriment to their course grade. This investigation was completed in compliance with all requirements of the Institutional Review Board for research with humans (Appendix F).

Rubric Development and Coding

Initial coding of Drawing 1 began with quantifying the structures and labels depicted in the student-generated drawings. A rubric was developed that attempted to assess the percent correctness of drawings collected in response to the first drawing task ("Percent Correctness Rubric", See Appendix G). Two raters independently coded a subset of 30 was coded using the "Percent Correctness Rubric" and both raters found this rubric problematic. The wording of the first drawing task was such that students did not need to include a predetermined number of structures or labels to convey understanding. Not only was this rubric misaligned with the drawing task, it also resulted in all errors having equal weight, which was undesirable. Therefore, this rubric was deemed inappropriate for further study.

Because our research goal was to explore how HA&P students thought about neuron communication, our next coding efforts were broadened to accommodate the individual ideas students depicted as well as variation in structures and labeling. To accomplish this, we used a simplified version of a rubric introduced by Ranaweera and Montplaisir (2010) to develop the "Accuracy Rubric", a rubric comprised of three categories: accurate, partially accurate, and inaccurate (Table 7). The decision to use the term "accurate" instead of "correct" or "complete" was informed by our initial coding attempts (administration of the "Percent Correctness Rubric"). In this study, students were limited by time, which may have limited the number of structures or labels depicted in their drawing, potentially limiting the correctness or completeness of the drawings. Also, if drawings were coded for "completeness", coding would have again been focused on the presence or absence of individual structure

Table 7. Accuracy Rubric.

Code	Criteria
Accurate	Everything drawn is accurate regardless of completion
Partially accurate	At least one component is accurate, at least one component is inaccurate
Inaccurate	Nothing provided in the drawing can be established as accurate

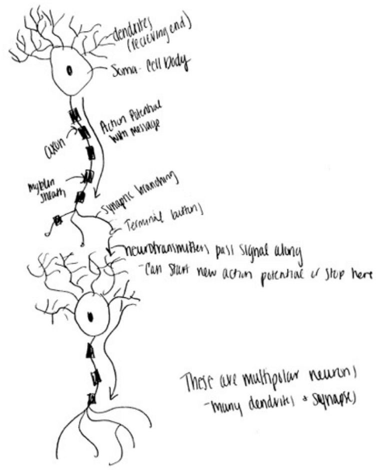
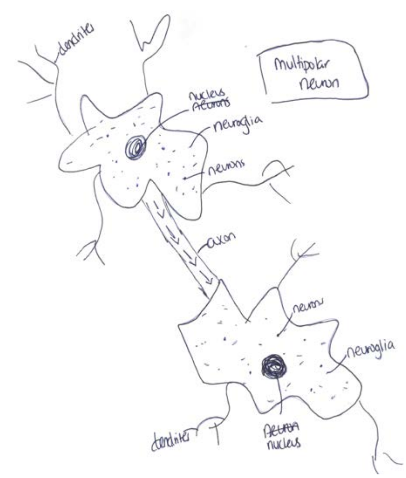
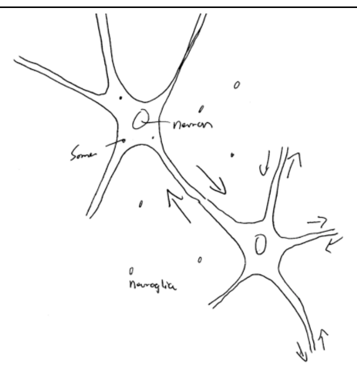
Administration of the accuracy rubric on Drawing 1 would result in qualitative coding of the anatomical relationships depicted in the student-generated drawings (Table 8). In order to adequately complete Drawing Task 1, we determined it was necessary to include two complete neurons; that is, two neurons with dendrites and axons that appeared distinctly separated from one another and placed appropriately with a synaptic cleft between them. In addition, students had to depict the direction of the signal to identify the orientation of the neurons. If students failed to create a drawing with all of those features but only had one error, they were considered partially accurate. If drawings made multiple errors, drawings would be considered inaccurate.

Table 8. Structural Accuracy Rubric for Drawing 1.

Code	Structural Features of Drawing 1
Accurate	- Two complete neurons - Labels were used accurately - Projections that were distinctly different
Partially accurate	- Only major error was made.
Inaccurate	- Missing or incomplete neurons - Projections were not distinctly different - Inaccurate labels

Example for all levels of Structural Accuracy of Drawing 1 can be found in Table 9. Within Table 9, example “a” was coded as accurate because the drawing contained two complete neurons separated by a synaptic cleft and all labels used in the drawing were appropriate. In addition, the dendrites represented in example “a” are distinctly different than the axon/axon terminals. In example “b”, the synaptic cleft is absent and the neurons are touching. Also, it is unclear if the axon is responsible for the output of the presynaptic neuron or if it is a part of the receiving end of the postsynaptic neuron. Example “c” was coded as inaccurate because all projections depicted have a similar appearance and appear to be structurally identical. Not only are the projections ambiguous, they are also merged together. The postsynaptic neuron seems to be a continuation of the presynaptic neuron resulting in the absence of a synaptic cleft and synaptic activity.

Table 9. Example for all levels of structural accuracy of Drawing 1.

Code	Structural Features of Drawing 1	Examples of Drawing 1
Accurate	- No major errors - two complete neurons - contains a synaptic cleft - correct labels - dendrites distinctly different than the axon/axon terminals	
Partially accurate	- One major error, for example: o no synaptic cleft o neurons are touching	
Inaccurate	- Multiple major errors, for example: o ambiquious projections o neurons are touching	

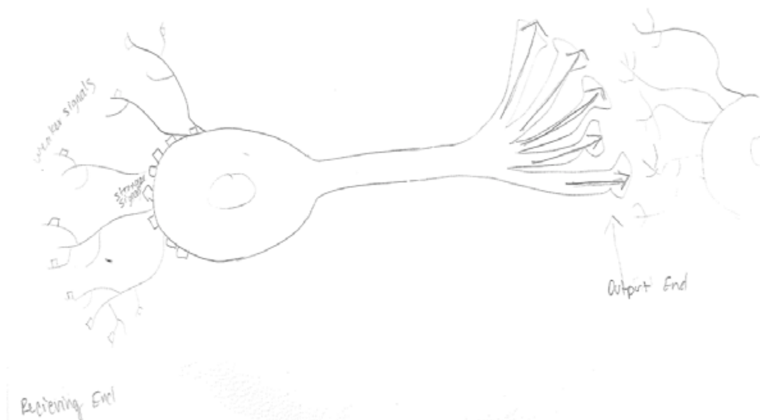
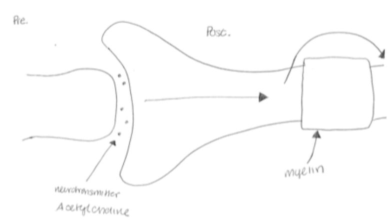
Administration of the accuracy rubric on Drawing 2 would result in qualitative coding of the anatomical relationships and physiological relationships depicted in the student-generated drawings (Table 10). In regards to the anatomical relationships, in order to adequately complete Drawing Task 2, we determined it was necessary to include at least one complete neuron and appropriate regions of neighboring neurons; that is, one neuron with dendrites and an axon such that their projections appeared distinctly different from one another and placed appropriately. Because Drawing 2 focused on summation instead of a whole pathway, we thought drawings did not have to include all parts of two neurons. Instead, students just had to provide enough information to convey how neurons are positioned in a pathway. For example, students could draw one complete neuron and the receiving end of the next neuron, placed appropriately, to be considered accurate. If a student failed to create a drawing with all of those features but had at least one error, they were considered inaccurate. Because students had received formal instruction on this content at the time this task was administered, we were less inclined to include a "partially accurate" category in the structural accuracy rubric. Also, we were interested in how the anatomical features of their drawing allowed for functional proficiency, and partially accurate anatomy would still have negative implications for functionality. For these reasons, we chose to collapse this rubric into simple "accurate" or "inaccurate" (Table 10).

Table 10. Structural Accuracy Rubric for Drawing 2.

Code	**Structural Features of Drawing 2**
Accurate	- One complete neuron - Projections that were distinctly different - Labels were used accurately
Inaccurate	- Missing or incomplete neurons - Projections were not distinctly different - Inaccurate labels

Examples of both levels of structural accuracy of Drawing 2 are shown in Table 11. Example "a" of Table 11 is an example of an accurate structural representation of Drawing 2. Example "a" contains one complete neuron that is properly orientated with the receiving end of the neighboring postsynaptic neuron and all labels provided were appropriate. Example “b” represents an inaccurate drawing due to the absence of a complete neuron and it is unclear if the receiving end of postsynaptic neuron is a dendrite, cell body, or axon.

Table 11. Example for all levels of Structural Accuracy of Drawing 2.

Code	Structural Features of Drawing 2	Examples of Drawing 2
Accurate	- one complete neuron - proper orientation - correct labels	
Inaccurate	- no complete neuron - unclear projections	

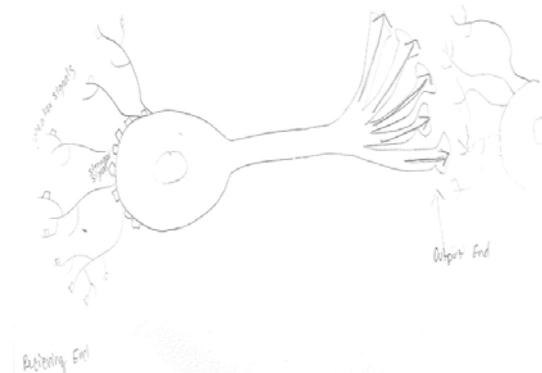
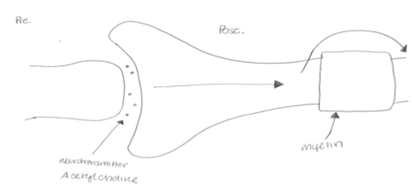
In regards to the physiological relationships depicted in Drawing 2, the functional rubric was built upon the Structure Accuracy Rubric for Drawing 2 (Tables 10 & 11). If a drawing was coded as structurally accurate and correctly depicted summation (variation in signal frequency or type), it was coded as functionally accurate. If a drawing was coded as structurally accurate and failed to depict summation correctly, it was coded as partially functionally accurate. If a drawing was coded as structurally inaccurate, it was coded as functionally inaccurate. Also, if a drawing was coded as structurally accurate but did not attempt to draw summation, it was coded as functionally inaccurate.

Table 12. Functional Accuracy Rubric for Drawing 2.

Structural Features for Drawing 2	Functional Features for Drawing 2
Accurate - One complete neuron - Projections that were distinctly different - Labels were used accurately	**Accurate** - Correctly demonstrate at least one type of summation
	Partially accurate - Incorrect summation
Inaccurate - Missing or incomplete neurons - Projections were not distinctly different - Inaccurate labels	**Inaccurate** - No attempt to draw summation

Examples of all levels of functional accuracy are shown in Table 13. Example "a" of Table 13 was coded as functionally accurate because it contains one complete neuron, an appropriate region of a neighboring neuron, and correct summation. Example "b" was coded as partially functionally accurate because it contains one complete neuron and an appropriate region of a neighboring neuron, but this drawing does not correctly depict summation. Example "c" was coded as functionally incorrect because it was not structurally accurate; therefore, it was incapable of being functionally accurate.

Table 13. Examples for all levels of Functional Accuracy of Drawing 2.

Code	Functional Features for Drawing 2	Examples of Drawing 2
Accurate	- one complete neuron - correct synapse - correct summation	
Partially Accurate	- summation complete neuron - correct synapse - incorrect	
Inaccurate	- structurally inaccurate	

While coding for structural accuracy of Drawing 1, we recorded notes on individual drawings, articulating errors and unique depictions (Examples of these notes can be found in Appendix H). At the end of this coding, a number of themes became apparent through our note taking. A list of these themes and examples can be found in Table 14.

Table 14.Themes from coding with Structual Accuracy Rubric for Drawing 1. A * indicates it was not observed more than once in the intial 30.

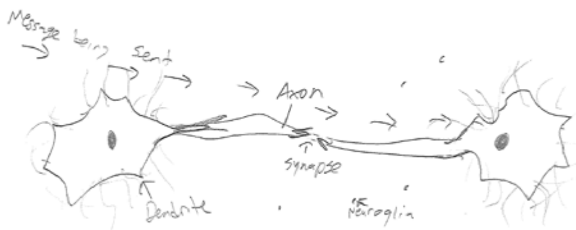
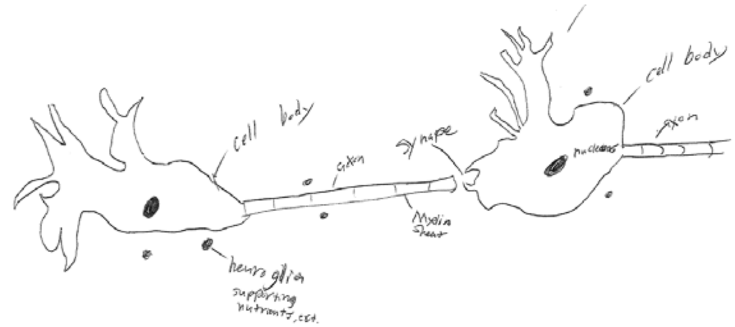
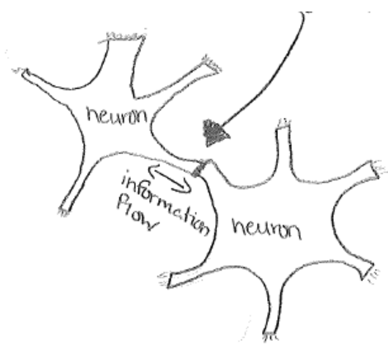
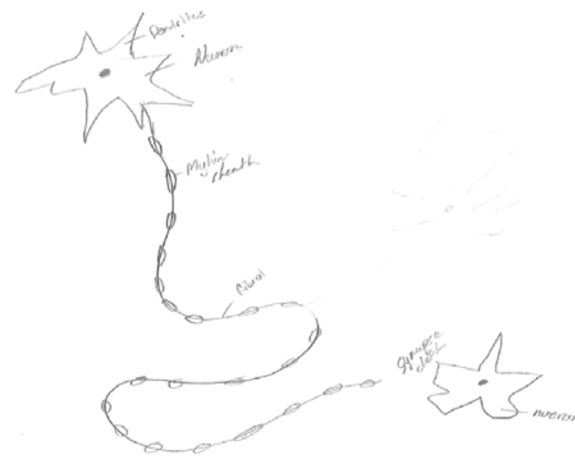
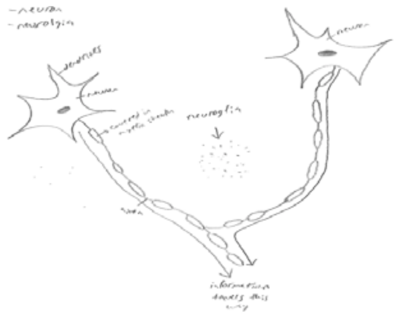
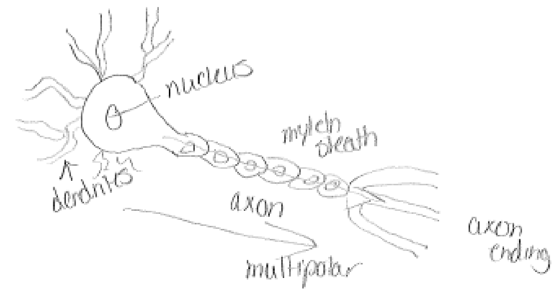
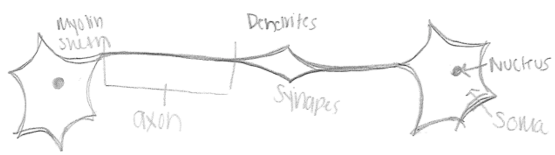
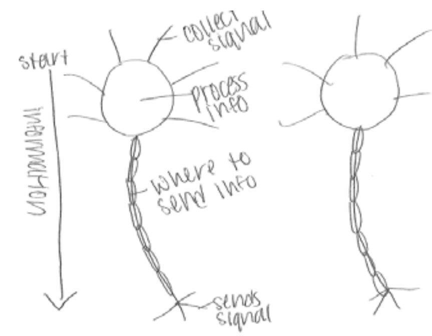
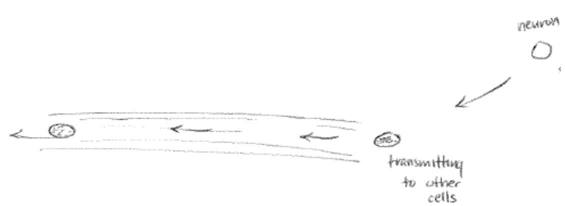
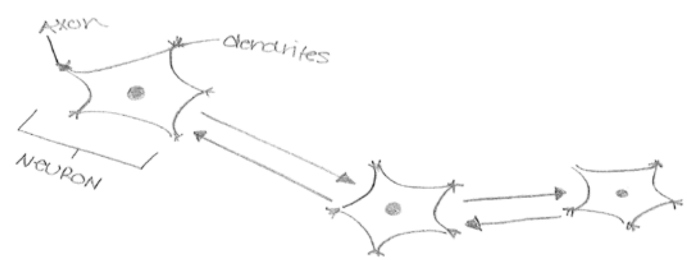
Theme	Example	Theme	Example
Axon-Axon		**No Direction**	
Bidirectional		**No Signal**	

Table 14. Themes from coding with Structual Accuracy Rubric for Drawing 1 (continued).

<table>
<tr><th>Theme</th><th>Example</th><th>Theme</th><th>Example</th></tr>
<tr><td>Converging Axons *</td><td></td><td>One Neuron</td><td>
</td></tr>
<tr><td>Dendrite-Dendrite</td><td>
</td><td>Side by Side</td><td>
</td></tr>
<tr><td>Hormonal *</td><td>
</td><td>Three Neurons *</td><td>
</td></tr>
</table>

If these themes were identified at least one time in an initial sampling (n=30), they were deemed appropriate for further coding and analysis, which resulted in seven themes: Touching, Bidirectional, Dendrite-dendrite synapse, Axon terminal-Axon terminal synapse, Side by side, No direction/no signal, and One neuron. Collectively, these themes were pertaining to or depicting some sort of error at the synapse, resulting in the development of a Synapse Rubric to characterize the types of errors students were presenting through their drawings. Of the remaining 7 themes, “Touching” was the most prevalent in the initial sampling, so the Synapse Rubric was developed to reveal the prevalence of this specific error (Table 15).

Table 15. Synapse Rubric for Drawing 1.

Code	Structural features for Drawing 1
Correct synapse	- 2 neurons - Synaptic cleft - Unidirectional synapse between axon/axon terminal and a dendrite/cell body
Touching synapse	- 2 neurons - No synaptic cleft, neurons were touching - Unidirectional synapse between axon/axon terminal and a dendrite/cell body
Other	- Drawings did not meet criteria above and the following errors were quantified: o Touching and another error o Bidirectional signal o Dendrite-dendrite synapse o Axon terminal-axon terminal synapse o Side by side o No direction/No signal o One neuron o Other

If the drawing contained two neurons with appropriate regions involved in the synapse and a synaptic cleft between the two neurons, it was coded as having a correct synapse. If it had the appropriate regions of two neurons involved in a synapse but they were touching, they were coded as touching. If a drawing contained other errors at the synapse, it was coded as other and then all errors present were documented.

Analysis

Four rubrics were used to facilitate the analysis of the two data streams, Drawing 1 (n=355) and Drawing 2 (n=311):

- Structural Accuracy Rubric for Drawing 1
- Synapse Rubric for Drawing 1
- Structural Accuracy Rubric for Drawing 2
- Functional Accuracy Rubric for Drawing 2

After generating the rubrics applicable for Drawing 1, two biology education research scientists individually coded 30 random drawings from Drawing 1. Any dissimilarity was discussed until cooperatively agreed upon. This process was repeated one more time, resulting in a percent agreement of 70%. Two additional subsets were coded in order to ensure a 70% agreement; one author coded the remaining drawings independently. The same researchers generated rubrics applicable for Drawing 2 and drawings collected for Drawing 2 were coded with the same procedure that was used for Drawing 1. When coding Drawing 2, four subsets were used to establish a percent agreement of 72%.

A Pearson's chi-square test was applied to determine if students are significantly better at drawing neural anatomy than physiology. Specifically, Pearson's chi-square test used data resulting from the Structural Accuracy Rubric for Drawing 1 and the Functional Accuracy Rubric for Drawing 2. A Pearson's chi-square test was also applied to determine if a student's depiction of "Touching" was dependent on their major or class status.

RESULTS

Administration of the two drawing tasks resulted in 355 responses for Drawing 1 and 311 for Drawing 2. The difference in sample sizes is due to fluctuations in class attendance. Also, because these questions were not a graded assignment, students who were present may have chosen not to participate. Both drawing questions did yield data from all major groups and classes enrolled in HA&P Fall 2012 (Tables 4 and 5).

Will Students Draw Neural Concepts in Human Anatomy and Physiology?

Of the 355 drawings completed and collected, 352 were codable. Three drawings were considered uncodable because they represented unrelated content and did not incorporate neural concepts. For example, one uncodable drawing incorrectly represented paracrine and autocrine signaling; therefore, the coding rubric pertaining to neural anatomy was not applicable. When presented with the second drawing task, all 311 were codable. Collectively, over 300 students completed drawings when presented with the drawing tasks, implying that drawing was engaging enough to elicit voluntary student participation.

How Accurately Do Students Draw Neural Anatomy?

Using the Structural Accuracy Rubric for Drawing 1, coding resulted in 69 drawings (19.4%) identified as accurate, 142 drawings (40.0%) coded as partially accurate, and 141 drawings (39.7%) coded as inaccurate. Coding of Drawing 1 resulted in almost 60% of student demonstrating at least some proficiency in neural anatomy prior to a formal class discussion. For Drawing 2, coding resulted in 268 drawings (86.2%) identified as accurate and 43 drawings (13.8%) coded as inaccurate (Table 16).

Table 16. Structural accuracy in Drawing 1 and Drawing 2.

Accuracy	**Structural accuracy for Drawing 1** (n=352)	**Structural accuracy for Drawing 2** (n=311)
Accurate	19.4% (69)	86.2% (268)
Partially accurate	40.0% (142)	N/A
Inaccurate	39.7% (141)	13.8% (43)

How Accurately Do Students Draw Neural Physiology?

All 311 drawings collected for Drawing 2 were coded with the functional accuracy rubric. Coding resulted in 3.5% of drawings (11) identified as accurate, 34.7% of drawings (108) identified as partially accurate, and 61.7% of drawings (192) identified as inaccurate (Table 17). Most students (96.5%) were unable to accurately depict the concept of summation when asked to do so by the drawing task and 61.7% of students (192) submitted drawings without including any features suggesting the process of summation.

Table 17 Functional accuracy of Drawing 2.

Accuracy	**Functional accuracy of Drawing 2** (n=311)		
Accurate	3.5% (11)		
Inaccurate	96.5% (300)	Inaccurate	34.7% (108)
		Absent	61.7% (192)

Are Students Better at Drawing Neural Anatomy than Physiology?

Students preformed significantly better on the structural component of Drawing 2 than on the functional component of Drawing 2 (X^2 = 425.96, df = 1, p < .001). Only 3.5% of drawings submitted (11) demonstrated proficiency in the concept of neural summation even though 86.2% of drawings (268) contained an accurate structural foundation for the summation task (Table 18).

Table 18. Structural accuracy compared to functional accuracy of Drawing 2.

Accuracy	**Structural accuracy of Drawing 2** (n=311)	**Functional accuracy of Drawing 2** (n=311)		
Accurate	86.2% (268)	3.5% (11)		
Inaccurate	13.8% (43)	96.5% (300)	Inaccurate	96.5% (300)
			Absent	61.7% (192)

When comparing performance across drawings, results from coding with the structural accuracy rubric for Drawing 1 compared with results from coding with the functional accuracy rubric for Drawing 2 suggest that preformed better on Drawing 1 than they did on Drawing 2 (Table 19). More students were able to create accurate representations of a structural concept (19.4%) than a functional concept (3.5%) prior to formal instruction (X^2 = 52.1488, df = 2, p < 0.001).

Table 19. Structural accuracy of Drawing 1 compared to functional accuracy of Drawing 2.

Accuracy	**Structural accuracy of Drawing 1** (n=352)	**Functional accuracy of Drawing 2** (n=311)
Accurate	19.4% (69)	3.5% (11)
Partially accurate	40.0% (142)	34.7% (108)
Inaccurate	39.7% (141)	61.7% (192)

What Other Alternative Conceptions About Neurophysiology Do Students Articulate Through Their Drawings?

Of the 355 drawings collected for Drawing 1, 352 were coded with the Synapse Rubric (Table 11). Three of the 355 drawings were not code-able as they contained no information or structures relevant to the task. Nearly 27% of drawings (94) were coded as containing an accurate synapse. The remaining 73% (n=258) of drawings contained one or more errors pertaining to the synapse. Of those drawings, 84.2% (192) contained errors that fit into the classifications identified via grounded theory (Table 20).

Table 20. Synapse accuracy of Drawing 1.

Synapse accuracy	**Synapse accuracy Drawing 1** (n=352)		
Correct synapse	26.7% (94)		
Touching synapse	8.5% (30)		
Other	64.8% (228)	Touching +	44
		Bidirectional	24
		Dendrite - Dendrite	28
		Axon Terminal – Axon Terminal	23
		Side by side	5
		No direction/No Signal	44
		One neuron	24

No other alternative conceptions were presented to the same degree as “Touching” (Table 21). The next most common alternative idea was “No Direction/No Signal”, characterized by drawings that did not contain an arrow representing a signal. This group consisted of 44 drawings, making up about 12.5% of the total number of drawings collected. These drawings were not explored further because it is not possible to discern how these 44 students think about synaptic transmission. Perhaps this group of students didn’t have any preconceived notion of how two neurons would communicate, but it is also possible that these students did not have enough time to complete this part of the task. It is also possible that some students failed to notice this part of the task when reading the instructions.

Table 21. Instances of error themes.

Code-able errors:	**Instances of code-able errors:**	**Percent of total drawings:**
Touching	74	21.0
No Direction/No Signal	44	12.5
Dendrite-Dendrite	28	8.0
Bidirectional	24	6.8
1 Neuron	24	6.8
Axon Terminal-Axon Terminal	23	6.5
Side by Side	5	1.4

Because this HA&P population is made up very distinct groups of students (See Table 4), we investigated how the decision to draw a “Touching” synapse was represented across majors (Table 22). Of the 74 students that drew neurons touching across a synapse, all major groups were represented. The percent of students within each major that committed these structural errors ranged from nearly 20% (nursing students) to about 4% (Life Sciences and other STEM majors). However, analysis revealed that the decision to draw neurons touching was independent of a students declared major (X^2 = 10.5165, df = 5, p = 0.06186). A similar analysis was done, investigating the relationship between class (i.e. freshman, sophomore, junior, and senior) and the “Touching” error, but again, it was not a significant relationship (X^2 = 3.0738, df = 3, p = *0.3804*).

Table 22. Instances of error themes across majors.

Majors	No. of Students who drew “Touching”:	Percent of Students who drew “Touching”:
Nursing	23	19.5
Pharmacy	19	17.9
Allied Sciences	11	14.1
Health and Wellness	15	13.4
Other	4	7.8
Life Sciences and Other STEM	2	3.7

DISCUSSION

Students Can and Will Draw Neural Concepts in Human Anatomy and Physiology

Undergraduate science curriculum rarely asks students to communicate their ideas through pictorial representation; however, student-generated drawings can be a useful tool to elicit student thinking. Both drawing tasks used in this study resulted in more than 300 voluntary responses from students enrolled in HA&P, indicating that students will draw when asked to do so. Data presented here suggest that in addition to obtaining a large number of voluntary responses, drawing tasks can result in drawings that are quite variable. Coding revealed that drawings were completed at different levels of accuracy and contained multiple unforeseen ideas, suggesting they are an individual product and are a quality data source.

Students Can Accurately Draw Neural Anatomy

Drawing 1

Data collected suggests HA&P students can draw anatomical features before receiving any formal instruction. The majority of students (59.9%) were able to accurately convey some part of neural pathways when presented with the task for Drawing 1, suggesting that most students have developed their own ideas about neural anatomy before entering a HA&P classroom and are able to communicate these ideas visually.

It is unclear where students would have gained any prior knowledge about neuron structure because unlike skin, bones, or muscle, students typically have very little experience observing neurons first hand. For example, students are able to touch their own skin and could easily have gained knowledge prior to receiving formal instruction. Therefore, drawing tasks asking about the differences between thick and thin skin could tap into a substantial degree of prior knowledge gained informally throughout the students' experiences, more than a somewhat abstract content area like the nervous system.

One could argue that students are unable to observe their own hearts, yet they can correctly depict its internal structure (Reiss and Tunnicliffe, 2001; Bahar et al., 2008; Mikkilä-Erdmann et al., 2012). However, it is appropriate to counter that there is a noteworthy difference between the extent of interaction a typical HA&P student has with the cardiovascular system compared to the nervous system prior to formal instruction. These structures have a substantial size difference. Students are far more likely to have witnessed an organ at a macro level, e.g. heart, brain, or intestine, than a cell at a microscopic level, e.g., neurons, muscle fibers, goblet cells. Also, students are introduced to the heart and heart function as early as elementary school (North Dakota Department of Public Instruction, 2014), long before any significant instruction on neuroglia. In addition to formal education, national initiatives like Million Hearts® from the U.S. Department of Health and Human Services and Go Red For Women® from The American Heart Association inform the general public about the importance of heart health and potentially imparting knowledge about heart structure through program visuals.

It is possible that students gained what knowledge they did have from the textbook readings, but the drawing tasks were designed so students had to create images not found in the textbook. As mentioned previously in the methodology, there was no reading check built into the curriculum, so it is unclear if the accurate/partially accurate drawings were a product of reading the assigned text or an experience occurring elsewhere, perhaps high school biology courses.

Drawing 2

Drawing task 2 asked students to represent anatomical structures and physiological events, however, unlike Drawing 1, this task occurred after students had received formal instruction on neuron structure. Therefore, Drawing 1 was assessing how students thought about neuron structure before instruction and Drawing 2 was assessing how students thought about neuron structure after instruction.

About 86% of students demonstrated proficiency in neural anatomy post instruction by creating student-generated drawings in response to a knowledge-level drawing assessment. This high success rate was somewhat expected when considering the nature of the drawing task. Drawing 2 was assessing student knowledge of neural anatomy and from existing literature we know that students are better able to communicate anatomical knowledge than they are functional knowledge.

Students Are Better at Drawing Neural Anatomy than Physiology

Students were fairly successful at Drawing 1, a pre-instruction student-generated drawing that assessed how accurately students think about neuron anatomy and a small degree of neuron physiology (one synapse). Students were significantly less successful at Drawing 2, a pre-instruction student-generated drawing that assessed how accurately students think about a great deal of neuron physiology (multiple synapses leading to summation) in conjunction with the structural content previously covered in lecture.

Student performance here was consistent with previous work investigating how students think about physiology in other body systems (Michael, 1998; Michael et al., 1999; Reiss and Tunnicliffe, 2001; Michael et al., 2002; Reiss et al., 2002; Prokop and Fančovičová, 2006; Carvalho 2009). When asked to represent a concept relying on a great deal of physiology, most students (96.5%) could not put forth enough correct information to suggest they understood the focal concept (summation). By synthesizing and applying previous research (Table 2), we can identify numerous cases of students being able to reason with structural concepts better than functional ones and the cardiovascular system can serve as a well-researched example of this disparity. A study conducted by Reiss and Tunnicliffe (2001) asked students to draw what they thought was inside their bodies with the aim of trying to expose the knowledge students had about organs and organ systems. This study resulted in over 90% of participating students (ranging in ages from 4 years old to college undergraduate students) drawing a cardiovascular structure (most often a heart) when asked what was inside them. This awareness of the structures of the cardiovascular system seems to be developed early on as indicated by the varying differences in the age of the targeted population yet the unwavering presence of these structures in the student work. This general knowledge also appears to stay consistent across stages of academic development as suggested again by the population sampled.

This physiology disconnect can be demonstrated using work done by Michael (1998). In this study, researches asked biology undergraduates to predict a physiological response and articulate their reasoning for that prediction through an instrument that contained both multiple-choice and open response questions. This instrument exposed numerous cases of incorrect reasoning accompanying correct predictions, one of which being the cardiovascular response to exercise ultimately revealing alternative conceptions about the cardiac pump. Similarly, Michael et al. (2002) demonstrate that students are able to make correct predictions about an organ's response to given variables but are unable to explain the mechanisms enabling the organ to perform the predicted response. Specifically, students struggled most with cardiac output and resistance. Carvalho (2009) also noted student's inability to provide a physiological explanation of chemoreceptors after providing a correct prediction regarding respiration.

Role of Teleological Thinking and P-prims in Human Anatomy and Physiology

Findings from Michael (2007) and Sturges and Maurer (2013) can be used to explain why we observe such dissimilarity in how accurately students think about anatomy and physiology in HA&P. The results from a survey administered to both instructors and students suggest that the complex levels of structural organization and the dynamic interactions occurring within and across levels can be credited for the increased difficulty of physiology. When looking at the specific survey questions, there was considerable agreement between instructors and students regarding the explicit factors contributing to physiology's difficulty, however, there was a noteworthy difference in how students and instructors think about the role of teleology in HA&P. Two hundred and seventy six HA&P students surveyed said that the teleological nature of the discipline is the most difficult variable to overcome when trying to learn new concepts (Michael, 2007). Where as when faculty (63) were presented with an almost identical survey, they ranked the teleological nature of the discipline 14^{th} out of 18 variables contributing to student difficulty in HA&P (Sturges and Maurer, 2013).

Teleological reasoning could be responsible for the high number of student errors in the present study. In Drawing 1, 21.0% of students drew two neurons in a linear pathway that were directly touching across the synapse (see Table 16, 21.0% includes all drawings coded as “Touching” and those coded as “Other-Touching +”). Recall that only about 19% of students created a correct response to Drawing 1 (Table 12). Therefore, more students were presenting erroneous ideas of touching neurons than those that were presenting an accurate representation of synaptic transmission. Because students were creating these drawings individually, its reasonable to say that “Touching” was the most common erroneous reasoning resonating with HA&P students enrolled in this course.

It is hypothesized that idea of “Touching” is the result of students using teleological reasoning to predict how neurons transmit a signal. This hypothesis is facilitated through the use of p-prims. Recall the work of Southerland and colleagues (2001), interview data suggests that students’ p-prims may be defining the “*need*” of physiology leading to teleological thinking (Figure 1). It is possible that students (21.0%) drew their neurons physically touching in Drawing 1 to satisfy the “*need*” of an internalized p-prim. Perhaps students are utilizing a sort of “*Contact*” p-prim. This “*Contact*” p-prim could be established from countless real-world examples of flow moving along a continuous path until there is a break in the path, stopping flow. Students may be tapping into previous experiences with common day examples of flow (i.e., water moving through pipes or electricity moving along a wire). Therefore, students may be using the “*Contact*” p-prim to frame how they think about the flow of neurotransmitters, suggesting that in order for the signal, or neurotransmitters, to move from one neuron to the next, the neurons need to be touching each other.

The “*Contact*” p-prim presented here aligns with other documented instances of teleological reasoning (Michael et al., 1999, 2002) in that they are building off of the physiological “*need*”. In the context presented here, synaptic transmission, the “need”, relies on the idea that neurons must be touching to allow information to flow (“*Contact*” p-prim).

As discussed previously, it is likely that students had very little knowledge about neurophysiology prior to the drawing assessments. Students cannot witness their own neurons synapsing, nor would they have observed this as a part of their K-12 education. Thereforee, it’s questionable where alternative conceptions would have developed, supporting the idea that students were implicitly applying their knowledge about other physical phenomena to explain how a neuron communicates with another neuron instead of tapping into pre-existing content knowledge.

Limitations

Student-generated drawings were the only data stream used in this study, thereforee, only one assessment type is used to answer five explicit research questions and ultimately reveal student thinking. The existing body of literature on student-generated drawings collectively promotes the use of drawings to expose student thinking (Table 3), however, both empirical and theoretical support is limited. A recent surge in drawing literature has reignited the potential of student-generated drawings becoming a mainstream data source but it's current state calls for additional data streams to be used in conjunction with student-generated drawings. Additional data streams could come in the form of interview data or written, explanatory responses. Asking students to provide a narrative to accompany the student-generated drawings would allow researchers to examine relationships depicted student-generated drawings in conjunction with an explanation for those relationships.

Students were assigned select passages from the textbook and these passages could provide them with all the necessary information to answer the concepts targeted by the drawing tasks. There were no reading checks incorporated into the curriculum, making it unclear if students actually completed the reading assignments. Without knowing if or how much students read before coming to class, one can not be certain that the knowledge presented in the drawings reflected their thinking prior to receiving any instruction. If a similar study were to be attempted again, reading checks would be a meaningful addition to the research design, ruling out the potential effect of the textbook.

Students had the option of enrolling in a concurrent laboratory course in addition to the HA&P lecture. Lab sections were offered on various days and times of the week and although course content was being covered in a similar sequence, the pace of the progression may have varied. It is possible that neural anatomy and neurophysiology could have been introduced to some or all of the students in lab prior to the administration of the drawing tasks, potentially influencing their responses. By ascertaining better demographic information, it would be possible to determine if students were coming into the pre-instruction assessment having already been exposed to targeted concepts, ruling out the potential effect of laboratory instruction.

Drawings were executed in a large auditorium with minimal supervision so it is quite possible that students may have discussed their responses with peers prior to creating their individual drawing. It is also possible that students copied a fellow classmate's response, resulting in an inaccurate representation of their own thinking.

Implications for Teaching and Learning

To someone unfamiliar with HA&P content, it may be hard to decipher why this idea of "Touching" is so problematic. Although it may seem like a small error, an faulty understanding of synaptic transmission could be troubling for a student trying to fully understand other physiological processes, perpetuating faulty reasoning well into his or her professional curriculum, maybe even into their career.

If students are not demonstrating a correct spatial relationship of the neurons involved in a synapse, it likely indicates they don't understand the characteristics of the structures involved, making it difficult to understand how neurons function at all. If a student draws two neurons touching at the synapse, it is also likely they don't have a clear understanding of the role of neurotransmitters (the chemicals responsible for transmitting a signal from one neuron to the next). Moreover, by drawing a "Touching" synapse, a student is demonstrating a faulty understanding of the structural and functional differences between dendrites and axon terminals. If student draws these two structures touching., it is likely they don't understand the role of the ligand-gated channels (sensitive to neurotransmitters) located on the dendrites. Because these channels are ligand-gated and not voltage-gated, a signal (neurotransmitter) initiates the opening of that channel, not the action potential from the previous neuron.

Because HA&P is a prerequisite for many health-related programs, it is important to consider how this idea of "Touching" could impact how students think about neurophysiology (a many source of regulation in the body) for the remainder of their education or even their career. For some programs (e.g. Exercise Physiology) HA&P may be their only exposure to neurophysiology. Because synaptic transmission is such an important part of their future profession (especially at the neuromuscular junction), it is important that all students have a solid understanding of this concept when completing this course.

At the practitioner level, drawings coded as “Other” by application of the Synapse Accuracy Rubric (Table 16) can inform how practitioners teach concepts in HA&P. Instructors can use data collected here to target any alternative conceptions or p-prims students may be using to explain neuron physiology. For example, coding revealed that 21.0% of students failed to acknowledge the existence of a synaptic cleft. Instructors can use this data to make evidence-based decisions when developing curriculum pertaining to synaptic transmission. For example, the evidence collected here would suggest that instructors can spend less time discussing neural anatomy in the classroom because a large number of students were already familiar with the structure (Table 12), making more time for instruction focusing on the spatial relationships of the nervous system and the physiology occurring between those relationships, a concept seeming to be much more difficult for students to understand (Table 13).

Not only did students demonstrate that they will participate in drawing assessments, they were also able to convey their ideas in response to a specific question, suggesting that student-generated drawings can be used as an assessment item. Through their drawings, students also provided thinking that may not have been exposed through a traditional multiple-choice format. For instance, almost 8% of students suggested that neurons are oriented dendrite-to-dendrite in a synapse and 6.8% of students were unable to indicate directionality across a synapse (Table 16). Albeit these values are somewhat small, collectively the “Other” alternative conceptions collected through Drawing 1 make up 64.8% of student responses, and these are the types of responses that would be difficult to expose with a multiple-choice format containing three or four instructor generated distractors.

Future Research

Evidence presented here coincides with the findings of previous studies, suggesting that undergraduates use teleological thinking to explain physiological phenomena in HA&P. However, this study joins only a handful of others to suggest teleological thinking is encouraged by p-prims. Very few authors have formally investigated the role of p-prims in biological sciences education and it appears none have explicitly sought to examine the influence of p-prims in how students reason in HA&P. Ample research has been targeted on the specific instances of student thinking being different from that of biological experts, even in the context of HA&P (Table 1), but virtually no research has been conducted to explore what it is about HA&P content, from the learner's perspective, that promotes teleological tendencies.

This study presents evidence suggesting that p-prims could be influencing the way undergraduates approach learning new concepts in HA&P. This outcome alone warrants further research into how p-prims influence student reasoning in HA&P, but the data presented here incite an even broader, potentially more impactful research question, what is the role of p-prims in undergraduate biology education?

Future work might begin by probing student reasoning on those concepts that seem to be counterintuitive in biology. Using HA&P as a model, one potential concept could be blood pressure regulation. Experts know that in times of low blood pressure, vasoconstriction is induced to increase blood pressure. Undergraduate HA&P students find this mechanism difficult to understand (Michael, 2002) and perhaps this difficulty is a result of previous, informal experiences with fluid dynamics (e.g. drinking out of straw with a small diameter is more difficult than drinking out of a straw with a wide diameter). Positive feedback mechanisms may also be counterintuitive to undergraduates learning HA&P. When we experience a change to our normal body conditions, we typically counteract the change, not enhance it. For example, if we are hungry, we do something to stop feeling hungry. We do not typically enhance the feeling of hunger. It may be that a student's experiences and the knowledge internalized as a result of those experiences are creating a roadblock for learning about the dynamic concepts covered in HA&P.

Studies identified in Table 1 have developed a pool of conceptual difficulties that may be the product of teleological thinking and p-prims. Future endeavors can be built off of these quantitative studies by collecting rich, quantitative data that elucidates the way students are coming to these erroneous answers, potentially pointing to the personal epistemology. Physics education researchers have had ample success with using interviews to gain insight into how students reason using intuitive thinking, providing biology education researchers with template that can serve as model for developing an understanding the role of p-prims in biology education.

CONCLUSION

This study used student-generated drawings to elicit how students think about neural physiology before receiving formal instruction. Data presented in this study reveal that students are able to communicate understanding of neural anatomy (synapse structure) far better than they can neural function (summation). The findings from this study coincide with previous work identifying student difficulties in HA&P but are novel in its contextual contribution. Prior to this study, very little was known about students' pre-instruction ideas about neural anatomy and physiology.

These drawing questions were not written with the intent of exposing any particular "alternative conception". Rather, these questions were created to bring to light any alternative conceptions students possessed about the nervous system. Similar to the drawing tasks used in previous studies (Tunnicliffe and Reiss,1999; Reiss and Tunnicliffe, 2001; Reiss et al., 2002) these questions used phrases that prompted students to make decisions about what they thought was important to answer the question.

Analysis of student-generated drawings revealed that prior to receiving formal instruction, a large number of students think neurons physically touch one another to transmit a signal, yielding evidence unlike anything previously documented in HA&P education literature. Because more students illustrated this erroneous way of thinking than any other, a hypothesis is presented to explain why this particular type or reasoning outweighed all others.

By integrating diSessa's theory of p-prims with the tendency of HA&P content to encourage teleological thinking, the "*Contact*" p-prim was conceived to explain the rationale behind the "Touching" response. The "*Contact*" p-prim describes how individuals recognize the relationship between a pathway and flow along that pathway, evoking the idea that if there is a break in a given pathway, flow will be interrupted. It is hypothesized that students in this study were using their intuitive knowledge about real-world physical events (the "*Contact*" p-prim) to frame how they think neurons "need" to touch in order for flow to continue across neurons, resulting in teleological reasoning enforcing an erroneous spatial relationship between two neurons.

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APPENDIX A. ALTERNATIVE CONCEPTIONS CITED

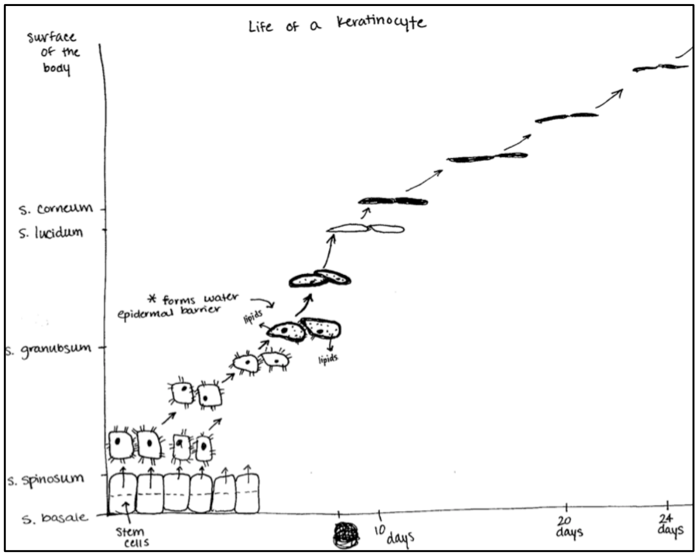
The alternative conceptions studied in Michael et al., 2002.

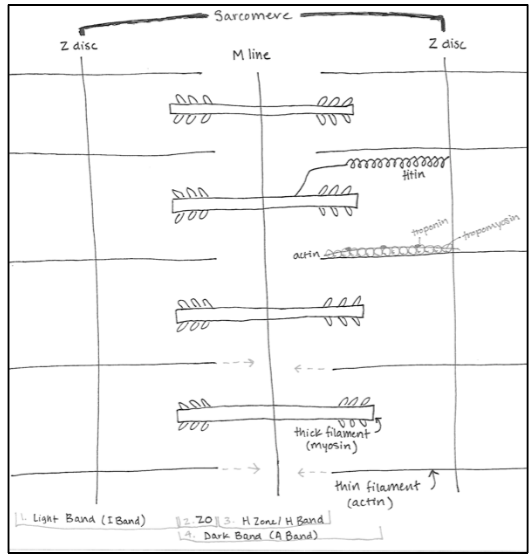
Michael et al. (2002)
CVDQ1: Vasoconstriction and Downstream Pressure Pressure/flow/resistance general model
CVDQ2: Hemorrhage and Venus Pressure Elastic structures general model
CVDQ3: Decreased Metabolism and Venous O_2 Content Mass balance general model
CVDQ4: Cardiac Output and Resistance Determinants of vessel resistance
CVDQ5: Arterial and Ventricular Contraction Structure/function relationships of valves in heart; cardiac cycle
CVDQ6: R and L Ventricular Output Circulation is closed, circular system; Frank-Starling
CVDQ7: Cap and Arteriolar Pressures Structure of circulation; pressure/flow/resistance
CVDQ8: Degenervate Heart Function (properties of) SA node; function of innervation of heart
CVDQ9: Timing of R and L Ventricular Contraction Structure/function of cardiac conduction system
CVDQ10: MAP is Regulated Variable Control general model
CVDQ11: Venous Return and Venous Volume Reservoir general model
CVDQ12: Flow in Pulmonary and Systemic Circulations Structure of circulation; Frank-Starling
CVDQ13: Cardiac Output/Stroke Volume Implications (qualitative) of multiplicative relationship defining CO

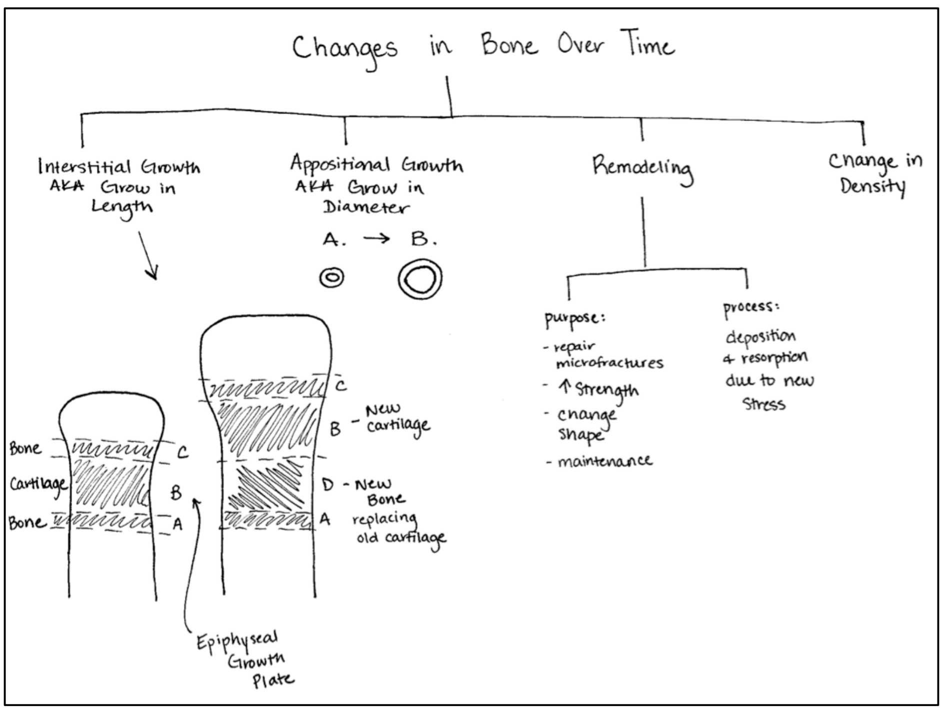
APPENDIX B. COMPARING INSTRUCTOR AND STUDENT RANKING OF PHYSIOLOGY BARRIERS

Human Anatomy & Physiology Difficulty Survey (Sturges and Maurer, 2013)	**Student Ranking** (Sturges and Maurer, 2013)	**Instructor Ranking** (Michael, 2007)
Understanding AP is based on (built upon) an understanding of physics and chemistry.	11	8
Physiological phenomena need to be understood at a number of different organizational levels at the same time (from the molecular to the whole organism).	5	5
Understanding AP requires the ability to think in terms of cause and effect.	2	1
Understanding AP requires at least some limited ability to think about dynamic systems.	3	3
AP, like other life sciences, seems to encourage thinking about things in terms of their purpose.	1	14
Much of our understanding of physiological mechanisms is communicated graphically or in other mathematical ways.	16	4
The language of AP is a mixed one, with many commonly used words taking on specific scientific meanings that are different from (sometimes opposite from) their lay meanings.	6	11
Textbooks typically present factual information, not explanations of phenomena or concepts.	12	10
Neither authors nor teachers stress the commonalities of function across organ systems ("common themes" or general models).	17	11
Teachers do a poor job defining and communicating learning objectives (what students should be able to do at the end of the class).	18	15
Teachers expect too many memorized facts and too little understanding at the same time.	13	12
Teachers and authors use language imprecisely, use too much jargon, an use too many acronyms, all to the detriment of learning.	15	16
In class, teachers talk (AP) too much and students talk (AP) too little.	10	13
Students believe that "learning" is the same thing as "memorizing".	4	2
Students compartmentalize (pigeon-hole) everything, failing to look for, or see, commonalities across organ systems or phenomena.	7	7
Students fail to appreciate how physiological mechanisms work together; they don't think about the respiratory system while learning acid/base balance because they studied it months ago and have passed the test on that subject.	8	6
Students assume that ALL physiological responses must benefit the organism.	14	17
Students tend to ignore graphs, tables and figures, when they attempt to use them they don't understand the meaning to be found there.	9	9

APPENDIX C. IN-CLASS DIAGRAMS







Examples of diagrams created with students in class during instruction. The top left image is an example from instruction on the integumentary system, top right is an example from instruction on the muscular system and bottom is an example from instruction on the skeletal system.

APPENDIX D. COURSE SYLLABUS

Human Anatomy & Physiology I (Biol 220) Fall

2012 Syllabus

Department of Biological Sciences, North Dakota State University

MWF 2-2:50 p.m. or TTh 8:00-9:15 a.m., Gate City Bank (formerly Stevens) Auditorium

A. Instructor Information

M.J. Kenyon, M.S.

209F Geosciences, 231-6156

mary.kenyon@ndsu.edu

Office Hours: to be posted on Blackboard

B. Course Description and Overview

This 3-credit course is an in-depth introduction to structure and function of human organ systems, cells, tissues, the integumentary system, the skeletal system, joints, muscle and muscular system, nervous tissue and nervous system, and the special senses.

Students will be introduced to human anatomy and physiology, moving from the simple to the complex, in both structure and function. The course will begin with basic organization, biochemistry and the cell and advance to higher structural and functional levels, such as organs and organ systems. This is the first in a 2-semester series, so some, but not all body systems will be examined. The unifying theme of the course will be homeostasis, the process by which the body maintains internal balance in response to changes in its internal and external environment.

C. Intended Course Outcomes and Their Relationship to General Education

This course will meet the requirements for the Science and Technology category of general education. Students will explore the connection between body structure and function, the link between homeostatic imbalance and disease, and the concept of emergent properties and its application to human anatomy and physiology.

Various student learning objectives, such as reading selected textbook topics, participating in class discussion and lecture, writing assignments, and exams will be used to support the following general education outcomes:

Outcome 5. Comprehend concepts and methods of inquiry in science and technology, and their applications for society.

Outcome 6. Integrate knowledge and ideas in a coherent and meaningful manner

D. Course Objectives

After successfully completing this course, students should be able to:

1. Explain how the body is organized at the microscopic and macroscopic levels.
2. Explain the concept of homeostasis and provide examples of homeostatic mechanisms.
3. Describe basic chemistry concepts that are significant to anatomy and physiology.
4. Describe the major chemicals associated with the body and their functions.
5. Describe the structure of a typical human cell and how it is organized.
6. Explain how substances can be transported in and out of human cells.
7. Describe the major tissue types and selected subtypes in terms of structure and function.
8. For each body system covered in this course, students should be able to:
    a. Describe the major organs and structures of the system and their locations in the body.
    b. Describe the basic functions of the system.
    c. Explain the physiological processes that occur as part of the system’s role in the body.
    d. Explain how each system interacts with other body systems.
    e. Explain how the system participates in maintaining overall body homeostasis.
    f. Explain how dysfunction in the system affects the body.
    g. Explain how the system is regulated intrinsically and extrinsically.

E. Required Student Resources

1. Textbook

Saladin, K. 2011. *Anatomy & Physiology, The Unity of Form and Function*, 6th Ed., McGraw Hill.

2. Connect, Anatomy & Physiology Revealed (APR), and Tegrity

These are companion online resources for the Saladin textbook that are provided by the textbook publisher.

Students are required to purchase access to these resources in order to complete all assigned work for this

class. A textbook package that includes all of these resources is available at the NDSU Bookstore. Access can also be purchased directly at the Connect website, which will be accessed through Blackboard. Lectures for this course will be recorded using Tegrity, where they will be available for students to view. APR is a virtual dissection tool. Students will be required to do a number of APR assignments for this class.

3. Blackboard

This online tool will be used extensively in this class as a way for the instructor to communicate with students, assign reading/suggested activities, post lecture outlines, post assignments and quizzes for credit, administer exams, and manage grades. Connect, Anatomy & Physiology Revealed, and Tegrity will be accessed directly through Blackboard. Students are expected to check Blackboard daily to stay informed about the class, to complete assigned work on time, and to utilize the study aids that will be made available.

F. Special Needs

Any students who need special accommodations for learning or who have special needs are invited to share their concerns or requests with the instructor as soon as possible.

Veterans and student soldiers with special circumstances or who are activated are encouraged to notify the instructor in advance.

G. Academic Responsibility

All work in this course must be completed in a manner consistent with NDSU University Senate Policy, Section 335: Code of Academic Responsibility and Conduct, which can be viewed at http://www.ndsu.nodak.edu/policy/335.htm.

Cheating is unacceptable and occurs any time a student receives credit for work that he/she did not do.

Human Anatomy and Physiology is a challenging course that places high demands on a student's time. Students in this class are expected to be serious about achieving academically, to be highly motivated, and to be willing to do the hard work required to succeed. Students are expected to seek out prompt assistance when needed to address any concepts that they do not understand. Assistance can be sought from the instructor or the teaching assistant during scheduled office hours or appointment, by phone, or by email.

Students are expected to attend class regularly. While in class, students are expected to be attentive and polite. The classroom is not a place for chatting with friends. Students are expected to ensure that their cell phones do not ring during class. Nevertheless, this will happen at some point during the semester. If your cell phone rings during class, turn it off at once to prevent further disruption for the rest of the class. DO NOT answer your phone and carry on a conversation in my classroom. If the call is an emergency, politely excuse yourself and leave the lecture hall before beginning your conversation. Computers are to be used only for note taking. Watching videos, checking Facebook, shopping, etc. can be very distracting for others around you who are trying to get an education. Part of the lecture hall may be designated as a no-technology zone to minimize the distractions inherent when computers are used in the classroom. ALL electronic devices must be stowed in backpacks or left at home on exam days.

Students should plan on spending enough time outside of class to read, listen to supplemental recorded lectures, and complete assignments. It is the responsibility of the student to establish a regular weekly study schedule, to work on the material assigned each week, and to complete all work on time. Deadline extensions will NOT be provided for students who do not complete assignments by the scheduled due date/time.

H. Course Requirements and Grades

The course material will be divided into 5 units, each covering several chapters of assigned material. Please note that the order in which we will cover material, does not coincide with the order that the material is presented in the textbook. Four exams will be administered during the semester, at approximately 4-week intervals. In-class writing assignments will be administered periodically. Learnsmart modules will be available at the beginning of each chapter, Anatomy & Physiology Revealed quizzes will be assigned periodically, and Blackboard quizzes will be assigned for each chapter. Assigned work will have due dates, after which the assignment can no longer be accessed or submitted for credit. Students are expected to keep up with deadlines by checking Blackboard for announcements and by keeping a calendar of due dates, upcoming exams, etc.

A total of 600 points can be earned in this course. Grades will be based on total points earned from 5 categories of work: exams, in-class writing assignments, Blackboard quizzes, APR quizzes, and Learnsmart modules. Letter grades will be assigned to students based on points earned on assigned work. Letter grades will be based on the following scale. **These are firm cut-off points and there will be NO adjustment of the scale.**

89.5% and above (537 or more points): A

79.5% - 89% (477-536 points): B

69.5% - 79% (417-476 points):	C
59.5% - 69% (357-416 points):	D
59% and below (356 points or less):	F

1. Exams: There will be four exams (see schedule below) that will, collectively, account for **400 points** in this class. Exams will focus on material presented in class and in recorded lectures, but may include some questions taken from assigned textbook material that is not covered directly in those lectures. Exams will consist of a combination of multiple-choice, matching, and true/false questions.

2. In-class writing assignments: Essay questions will be assigned periodically during the semester while in class. A limited amount of time will be allocated during a given lecture to the completion of these assignments (usually 15 minutes). At least 5 writing assignments will be provided (each worth 20 points). You can earn up to **80 points** on these assignments, so your top 3 scores on the first 4 essays, plus your score on the final essay will be counted towards your letter grade. If you miss an assignment because you are absent on the day that it is administered, it will count as your low score. There will be NO opportunity to make-up any missed writing assignments. You will be advised at least one class period ahead of an upcoming assignment.

3. Blackboard quizzes: Blackboard quizzes will usually be posted weekly. These quizzes will be available for a limited number of days, and students will have a limited amount of time to take the quizzes once they have been opened (i.e. they will be timed).

Blackboard quizzes will be graded as follows: 5 points for earning at least 90% on the quiz, 4 points for earning between 80-89.5%, 3 points for earning between 70-79.5%, 2 points for earning between 60 and 69.5%, and no points for earning less than 60%. There will be 14 quizzes posted during the semester. You can earn up to **50 quiz points**, and you can take as many of the quizzes as needed to attempt to earn the maximum number of points. A minimum of 10 quizzes, with 90% or higher performance will be needed in order to earn the full points.

4. Anatomy & Physiology Revealed (APR) Quizzes: There will be 8 APR quizzes assigned periodically during the semester. APR will be accessed through the Connect website. Each quiz will have a set due date by which time it must be completed and the results posted to Blackboard. Each quiz will be worth 5 points. You will earn credit for achieving at least a particular minimum score (usually 22 out of 25) on the quiz. NO partial credit will be given. You can earn up to **35 APR points**, so you must complete 7 of the 8 quizzes with at least a minimum score in order to earn full credit.

5. Learnsmart modules: Learnsmart modules will be assigned for 7 chapters. These modules are found at the Connect website and include a series of questions to test your basic knowledge about a particular chapter from the Saladin textbook. Each module will remain open for a set period of time. Their use in this course is designed to encourage you to read the textbook and keep working steadily on the course materials.

Each assigned Learnsmart module will be worth 5 points, and you can earn up to **35 points** for completing all of the assigned modules. In order to earn the points, you must complete 100% of the module. Learnsmart modules will be available for the remaining chapters we will cover, but completion of them will be optional (i.e. no points earned for completion).

I. Exam Schedule

There are 2 sections of this class, and exams must be administered to both sections consecutively. Unfortunately, the sections meet for lecture on different days. This has necessitated scheduing of exams at times when classes don't normally meet. I have selected Tuesday or Thursday mornings between 7:00 a.m. and 8:15 a.m. as the best time to do the exams. Students who are enrolled in the TTh 8:00 a.m. section of the class will take their exams during their normal class time. Students who are enrolled in the MWF 2:00 p.m. section of the class will begin their exams at 7:00 a.m. Some of the MWF students may be able to take their exam with the TTh group, depending upon seating availability. **If you cannot take the exams during either of these times, you must notify me immediately at the beginning of the semester to discuss the situation. You will also need to provide written verification of the conflict that makes it impossible for you to attend the exams during these times.**

Students will NOT be allowed to take the regular exams at any time other than the scheduled time. Any exam taken at an alternative time will be a make-up exam and will consist primarily of short essay questions. Approval of make-up exams will be at the discretion of the instructor. Make-up exams will only be considered in case of a documented emergency or mandatory school-related function. Written documentation of the reason necessitating absence from the exam must be provided in order for any consideration to be given. The exams have been scheduled for the following dates:

Exam 1: Thursday, September 13, 2012

Exam 2: Tuesday, October 9, 2012

Exam 3: Tuesday, November 6, 2012

Exam 4: Thursday, December 6, 2012*

*Please note that this exam will be taken during the last week of classes. There will be no final exam. The time set aside for final exams will be used to complete the last writing assignment. Completion of that writing assignment will be mandatory. Your score from that assignment WILL be included in the 4 scores that will be used to determine your letter grade.

J. Course Outline

The following provides a general idea as to the order that topics will be covered in this class. Specific dates have not been assigned to each topic in order to maintain flexibility in the course. Please note that the following units are NOT exam units. In other words, they do not reflect the content that will be covered on individual exams. Exam coverage will be based on the amount of material we have covered prior to the scheduled date for each exam. You will be advised as the semester proceeds, what material will be covered on each exam.

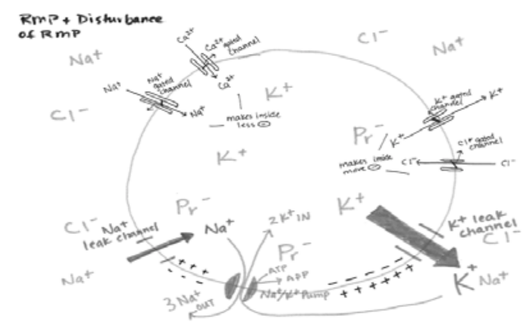
1. Overview & the integument, including material from Chapters 1-6 (excluding Chapter 4)
2. Regulation of body functions, including a thorough look at nervous tissue and electrical signaling (Chapter 12)
3. The musculoskeletal system, part 1: muscular tissue & the anatomy/function of muscles (Chapters 10 & 11)
4. The musculoskeletal system, part 2: skeletal tissues, & the anatomy/function of the skeleton (Chapters 7,8,& 9)
5. Organization of the Nervous System, including the brain, spinal cord,nerves, and sense organs (Chapters 13-16, possibly some material from Chapter 12)

APPENDIX E. INSTRUCTION TIMELINE

Neuron Anatomy

1. Introduced channel types and flow directionality while students constructed neurons, facilitated through instructor-generated drawing containing labels and arrows	
2. Presented textbook renditions of neuron anatomy to help students connect instructor-generated drawings with textbook figures	*Fig. 12.4a*
3. Introduction to myelin and its structural properties, facilitated through textbook figures	*Fig. 12.4c & 12.7*
4. Presented alternative neuron structure and structural classifications through textbook figures	*Fig. 12.5*

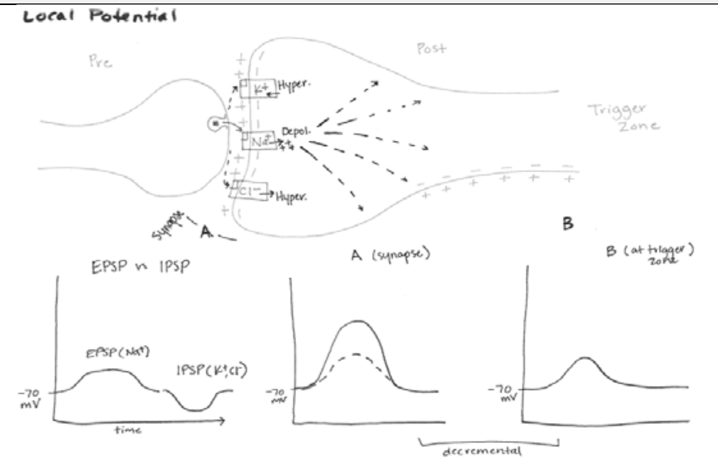
Role of Ions and Membrane Potentials in Communicating Neurons

5. Diagramed how resting membrane potential is established by indicating ion flow with arrows 6. Demonstrated how resting membrane potential can be disrupted by adding channels and ion flow	

Graded Potentials

7. Identified the types of channels present in the membrane of dendrites and the resulting ion flow

8. Discussed the effect of ligand-mediated ion flow on resting membrane potential at dendrites, illustrated graphically



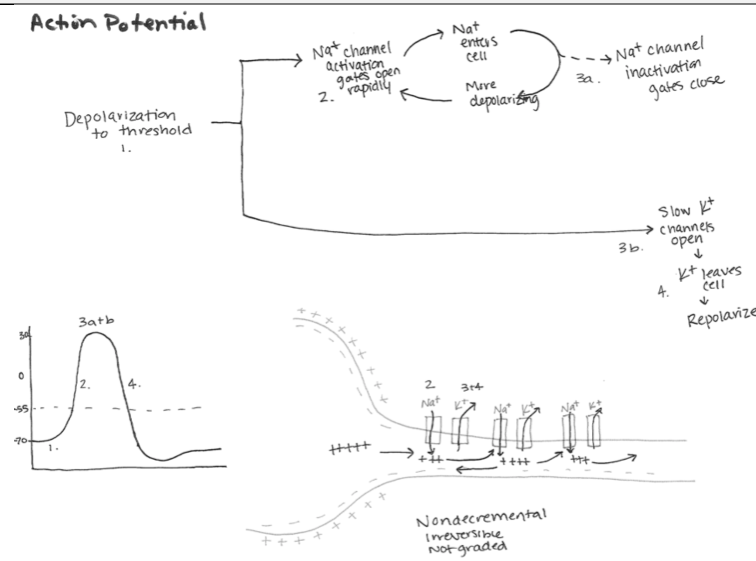
9. Provided textbook renditions of graded potentials to help students connect instructor-generated drawings with textbook figures

Fig 12.12

Action Potentials

10. Identified the types of channels present in the membrane of axon,

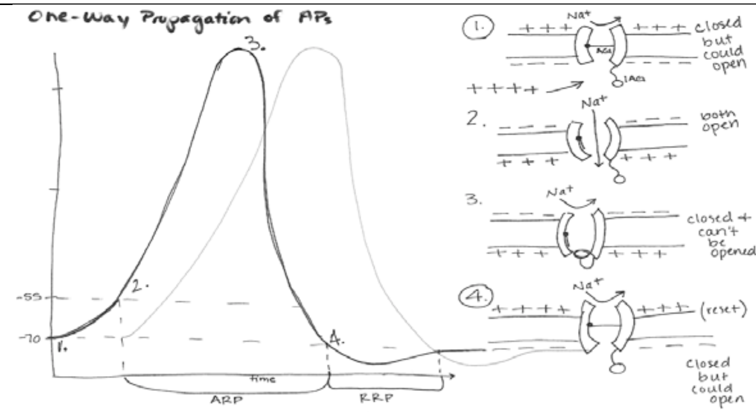
11. Discussed the effect of voltage-mediated ion flow on resting membrane potential at the axon



Action Potentials (Continued)

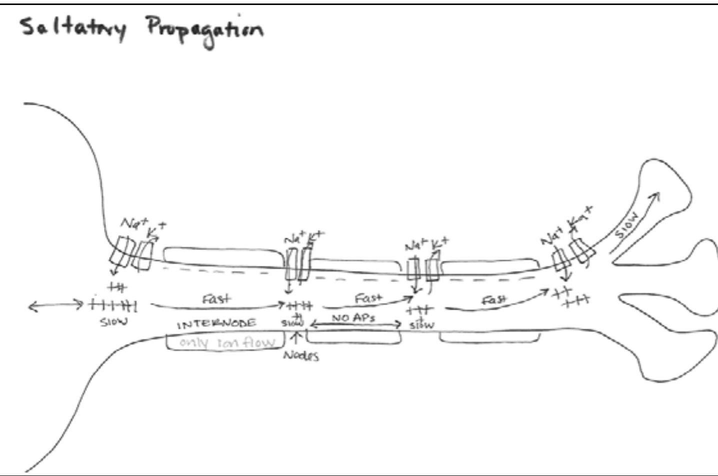
12. Provided textbook renditions of action potentials to help students connect instructor-generated drawings with textbook figures — *Fig. 12.13*

13. Described the importance of one-way propagation and discussed the role of the absolute refractory period through diagraming ion flow pictorially and graphically



14. Provided textbook renditions of one-way propagation of action potentials to help students connect instructor-generated drawings with textbook figures — *Fig. 12.15 & 12.16*

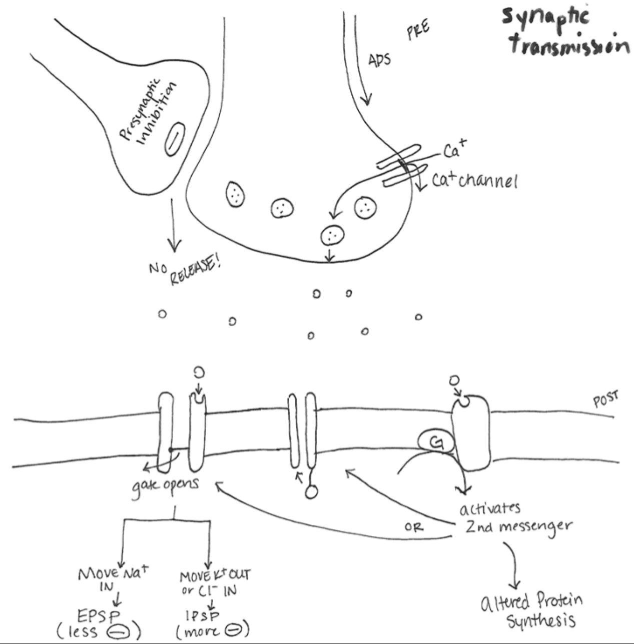
15. Described the role of myelin in action potential propagation by depicting ion flow along an axon



16. Provided textbook renditions of ion flow and myelination to help students connect instructor-generated drawings with textbook figures — *Fig. 12.17a & 12.17b*

Synaptic Transmission

17. Described the release of neurotransmitters from a presynaptic neuron



18. Noted the diffusion of neurotransmitters across the synaptic cleft

19. Identified receptor and signal types (IPSP vs. EPSP) on postsynaptic neuron

20. Provided textbook renditions of synaptic transmission and signal type to help students connect instructor-generated drawings with textbook figures

Fig. 12.20 and 12.24

APPENDIX F. IRB APPROVAL DOCUMENT

NDSU NORTH DAKOTA STATE UNIVERSITY

March 28, 2014 FederalWide Assurance FWA00002439

Lisa Montplaisir
Biological Sciences

Re: IRB Certification of Exempt Human Subjects Research:
Protocol #**SM14224 , "Making sense from student generated drawings"**

Co-investigator(s) and research team: **Tara Slominski**

Certification Date: 3/28/14 Expiration Date: 3/27/17
Study site(s): **NDSU**
Funding: **n/a**

The above referenced human subjects research project has been certified as exempt (category # 1) in accordance with federal regulations (Code of Federal Regulations, Title 45, Part 46, *Protection of Human Subjects*). This determination is based on protocol materials (received 3/28/14).

Please also note the following:

- If you wish to continue the research after the expiration, submit a request for recertification several weeks prior to the expiration.
- Conduct the study as described in the approved protocol. If you wish to make changes, obtain approval from the IRB prior to initiating, unless the changes are necessary to eliminate an immediate hazard to subjects.
- Notify the IRB promptly of any adverse events, complaints, or unanticipated problems involving risks to subjects or others related to this project.
- Report any significant new findings that may affect the risks and benefits to the participants and the IRB.
- Research records may be subject to a random or directed audit at any time to verify compliance with IRB standard operating procedures.

Thank you for your cooperation with NDSU IRB procedures. Best wishes for a successful study.
Sincerely,

Kristy Shirley

Kristy Shirley, CIP, Research Compliance Administrator

INSTITUTIONAL REVIEW BOARD
NDSU Dept 4000 | PO Box 6050 | Fargo ND 58108-6050 | 701.231.8995 | Fax 701.231.8098 | ndsu.edu/irb

Shipping address: Research 1, 1735 NDSU Research Park Drive, Fargo, ND 58102

NDSU is an EO/AA university.

APPENDIX G. PERCENT CORRECTNESS RUBRIC

1. Look at only the structures drawn and the labels for each of those structures. Ignore anything that is not a label of a structure.

2. Determine how many structures and labels are present in the drawing and determine the total number of items present on each drawing (structures + labels).

3. Categorize each item as either correct or incorrect. Use the question below to determine if an item is correct.

4. Determine the percent of items that are correct on the drawing.

5. Use the ranges below to assign a numerical value to the drawing.

100%	= **10**
90% - up to 100%	= **9**
80% - up to 90%	= **8**
70% - up to 80%	= **7**
60% - up to 70%	= **6**
50% - up to 60%	= **5**
40% - up to 50%	= **4**
30% - up to 40%	= **3**
20% - up to 30%	= **2**
10% - up to 20%	= **1**
0% - up to 10%	= **0**

6. If the submission does not include a drawing or if the drawing is not an appropriate submission, label the drawing “**NC**” for “not code-able”.

APPENDIX H. DESCRIPTIVE CODING NOTES

Drawing	Observation Notes	Structures and/or Labels Included
1	synapse is incorrect and as a result, the direction of flow is incorrect	neurotransmitter, dendrites, nucleus, cell body, myelin sheath, axon, synapse, sensory neurons
2		soma/cell body, dendrites, nucleus, axon, sensory neurons
3	no directional flow, synapse is incorrect, weird shape	neuron, synapse, neuron
4	no directional flow, synapse is incorrect, weird shape	dendrite, neuroglia, axon, neuron
5	synapse is incorrect, no labels	NO LABELS
6	synapse seems to occur between cell body and axon, no directional flow, weird shape	neuroglia, synaptic junction, myelin sheath
7	dendrites send it down an axon to the cell body	cell body, axon, dendrites
8	signals are flowing into one another, no other labels	NO LABELS
9		soma, dendrites, nucleus, axon hillock, axon w/myelinated sheaths, synapse, terminal buttons, electrical signal, intermediate neurons
10	synapse is incorrect	dendrites, synapse, cell body, myelin sheath, nucleus, axon ending
11		cell body, axon, synapse, synaptic cleft, neurotransmitters, dendrites
12		dendrites, cell body, axon, synapse
13	terminal knobs, what happens at the end of the axon, synapse?	axon, myelin sheath, dendrites, soma, nucleus
14	incorrect and incomplete, draws neurons like circles	synapse, neurotransmitter, neuron
15	dendrites are sending signals to axon, information flow is incorrect	neuroglia, cell body, nucleus, dendrites, synapse, axon, chemical messengers, nucleus, cell body
16	only 1 neuron	dendrites, neurons, axon, node of Ranvier, internodes, myelin sheath, Schwann cell
17	information is flowing the wrong way, not sure what "carl" is?	axon, body, dendrites, nucleus, synapse

18	information flow is incorrect	nucleus, cell body, neuroglia, dendrite
19		dendrites, soma, nucleus, axon
20	strange but not incorrect	dendrite, myelin sheath, axon, synapse
21	these neurons seem to be 1 large neuron	neuron, neuroglia, axon
22	kites? what they chose to include was technically correct	dendrites, cell body
23	it appears that they are just a circle, no resemblance to a neuron	dendrites, nucleus
24	not 2 neurons, signal flow is incorrect, gap junctions???	brain, gap junctions, synapse, axon, axon terminal, soma, dendrites
25	myelin sheath doesn't look like anything	dendrites, cell body, nucleus, myelin sheath, axon, synapse, neurotransmitters
26	not 2 neurons, no signal flow, dendritic cell	axon, nucleus, dendritic cell
27	only 1 neuron, internodes and nodes of Ranvier seem to be the same thing	dendrites, soma, nucleus, nucleolus, axon, axon collateral, node of Ranvier, internodes
28	unsure if dendrites are sending or receiving the signal, or both	nucleus, dendrites, soma
29	only 1 neuron, no signal flow, axon collateral is inappropriate	dendrites, nucleus, nucleolus, soma, internodes, axon collateral, myelin sheath
30	neuroglia instead of cell body, synaptic gap?	dendrites, neuroglia, nucleus, synaptic gap
31	they seem to be touching	dendrites, nucleus, axon, myelin sheath, node of Ranvier
32	only 1 neuron	cell body, nucleus, dendrites, axon, myelin sheath
33	signal is shown to move "back and forth", dendrite is sending and receiving a signal, this looks like those ink blots	neuron, dendrite, synapse, axon,