VISUAL LITERACY IN ANATOMY

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Dedication

This dissertation is dedicated to Laura and Simon. The two of you have been the most supportive and loving family I could ever want.

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VISUAL LITERACY IN ANATOMY

All branches of anatomy (gross anatomy, histology, neuroanatomy, and embryology) involve significant amounts of visual identification. Understanding the spatial relationship and visual representations of anatomical structures forms the basis for much of anatomy education, particularly in laboratory courses. Students in these courses frequently struggle with the visual aspects of identification, and many lack the metacognitive awareness to identify this problem. The research presented here details a series of experiments designed to elucidate the factors involved in students' difficulties with studying the visual aspects of anatomy. All of the research projects discussed involved surveying students about their specific study habits. Student populations surveyed include first-year medical students and undergraduates in anatomy, physiology. These populations were surveyed about their study habits in each course, and their level of familiarity with visual learning. Additionally some populations were given a mental rotation test to assess their spatial abilities. These survey data were then correlated with course grades in an effort to determine the most successful study strategies. Active learning approaches (including student-produced drawings) were most strongly correlated with high course grades. However, efforts to teach lower-performing students active learning skills did not produce significant results, possibly due to the lack of a metacognitive component in this instruction. The results of each project indicate a lack of good study skills among students at all levels of anatomy instruction, and highlight the need for more instruction in how to study for anatomy, including metacognitive awareness, especially focused on the visual aspects of the course.

Valerie Dean O’Loughlin, Ph.D., Chair

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CHAPTER 1: Introduction

Success in anatomy courses requires a variety of study skills, including the ability to understand visual representations of anatomical structures. Students in anatomy courses are often provided with instruction in how to study, but this instruction rarely includes a visual element. That is, if visual learning is recommended to students, the recommendation may not include all of the information a student needs to confidently engage in visual learning. Consequently, students are often left to interpret images using their existing (often inadequate) visual skills. It is the goal of this multi-faceted dissertation project to examine the visual skills students bring to anatomy courses, to examine if certain prior visual skills are necessary (or sufficient) to succeed in anatomy, to determine if students leave anatomy classes with a greater development of visual skills, and to explore methods of teaching visual skills to anatomy students.

The current literature in anatomy education has many examples of teaching spatial ability (with few devoted to visual literacy) to students (Keehner et al. 2006, Provo et al. 2002, Lufler et al. 2012, Luursema et al. 2008, Boudreau et al. 2008, Hegarty et al. 2009, Wanzel et al. 2002, Fuks et al. 2009, Garg et al. 2001, Lawrence et al. 2014, Roach et al. 2012, Roach et al. 2014, Roach et al. 2016, Backhouse et al. 2016, Pickering 2015, Mione, et al. 2013), but these are examples of specific experimental implementations, or research on new types of visual representations. There is very little published literature regarding the basic visual instruction given to students (Bardes et al. 2001). That is, outside of specific visual learning interventions, it is unclear how students are instructed to understand images in anatomy courses. While these specific interventions (described in the above citations) provide valuable information about how students use images in learning, the information about student use of images outside of experimental designs is lacking. Data collected from course syllabuses and instructor comments (only from five courses at Indiana University, see course descriptions in chapter 3) indicates that visual approaches to learning are encouraged, but no class time is spent developing the skills needed to engage in visual learning (see appendices for course syllabuses). The published literature in visual learning indicates that acquiring the skills needed to understand images is not a passive process, and specific instruction is required for students to access the informational content of images (Titus and Horsman 2009 is a notable exception, this paper demonstrated significant passive acquisition of spatial ability in geology students). For a detailed summary of the published literature concerning visual literacy and spatial ability in anatomy students, see chapter 2.

The research presented in this dissertation is divided into three main components- examining students study skills, comparing visual literacy and spatial ability skills to course performance, and improving visual literacy and spatial ability in students. These three main components are further discussed in the following paragraphs, with detailed methodologies and results discussed in chapters 4-8.

Having reviewed the existing literature, and finding a lack of information about the visual literacy skills naïve students bring to their anatomy courses, the first step of this dissertation project was to determine what our students are doing when studying for anatomy. By examining their study habits, their familiarity and comfort with visual literacy and spatial ability can be inferred. Knowing what the students do to study, when not provided with any explicit instruction in study methods, helps to fill the gap defined above. That is, what kind of visual literacy skills do students bring to class? The first phase of dissertation research used early-semester surveys to determine what kind of study techniques students are using, without any specific training in how to study. Chapters 4-6 explore this question in greater detail, with detailed methodology and results included.

The second step in this dissertation was to determine if visual literacy (and spatial ability) skills change during an anatomy course. Acquisition of spatial ability (but not visual literacy) has been documented (Keehner et al. 2006, Provo et al. 2002, Lufler et al. 2012, Luursema et al. 2008, Boudreau et al. 2008, Hegarty et al. 2009, Wanzel et al. 2002, Fuks et al. 2009, Garg et al. 2001, Lawrence et al. 2014, Roach et al. 2012, Backhouse et al. 2016, Pickering 2015, Mione, et al. 2013) in a variety of science courses, including anatomy, but often only through a specific pedagogical intervention. Some studies (Titus and Horsman 2009) have shown a passive acquisition of visual skills simply by taking a course, but this has not been frequently repeated. This part of the dissertation work used early- and late-semester surveys and mental rotation tests (MRT) to examine passive acquisition of visual skills. Chapters 5-6 deal with this question in greater detail, including detailed methodology and results.

The final major facet of this dissertation work explored ways of instructing students in using visual literacy and spatial ability skills in their studying. There are many published studies describing the benefits and drawbacks of specific pedagogical interventions in teaching visual literacy or spatial ability (Keehner et al. 2006, Provo et al. 2002, Lufler et al. 2012, Luursema et al. 2008, Boudreau et al. 2008, Hegarty et al. 2009, Wanzel et al. 2002, Fuks et al. 2009, Garg et al. 2001, Lawrence et al. 2014, Roach et al. 2012, Backhouse et al. 2016, Pickering 2015, Mione, et al. 2013 are just a sample, for a full accounting of the various debates in the visual learning literature, see chapter 2). A number of contradictions are apparent in the literature regarding the teaching of visual skills. For example, the literature examining two-dimensional vs. three-dimensional images, static vs. animated images, or interactive vs. passive representations; contains support for any of these visual representations as the 'best' for teaching different facets of anatomy. It may be that all types of visual representations are useful in different contexts, or with different students populations, or maybe the instruction in visual learning is the important feature, and the type of image is less important than the underlying visual skills being conveyed in these different instructional contexts. Sadly, this question is still unanswerable. The existing literature has yet to converge on a consensus, and this dissertation project does not argue for one variety of image or instructional technique over another, but rather makes the case for spending time providing instruction in visual literacy and mental rotation as part of an anatomy course. To make that case, two different methods of teaching visual literacy were used. The first method included in-person drawing instruction combined with anatomy content. The second method used a series of web-based drawing tutorials which allowed students to draw along with a narrator explaining neuroanatomy content. Both of these methods showed some increase in student use of visual study skills, again indicating that the teaching of visual literacy, *at all*, may be more important than the *specific type* of images being used. This result is seen many times in the literature review in chapter 2 (under subheading "Non-discipline specific spatial ability"). Full details of the pedagogical interventions used to teach spatial ability and visual literacy can be found in chapters 7-8 with methodology and results.

Definitions

Before continuing, it is worthwhile to carefully define some of the terms that are used frequently throughout the following projects. *Study skills*, *study habits*, *visual skills, visual learning,* and *visual study skills* are some terms with variable definitions, and they may be used by different authors in different ways. The following paragraphs define these terms as they are used in the context of this research.

Study skills, study habits, and study strategies are sometimes defined differently (Credé and Kuncel 2008, Morehead et al. 2016), but in this research they are used interchangeably. Study skills (a.k.a. study habits or study strategies) are patterns of effort and techniques used by students outside of class to learn course material and prepare for exams (Schutte 2013, Husmann et al. 2016, McGuire 2015).

Visual skills are the entire set of mental processes related to understanding the visual world, and include spatial ability and visual literacy. This definition is unique to this dissertation, as the term 'visual skills' has been used by different fields to refer to any and all types of vision. (For example, researchers in human vision use 'visual skills' to refer to normal operation of the visual apparatus and brain, see Achtman et al. 2008). Visual skills (as used in this dissertation) will be discussed at length in the literature review, including the historical arguments about definitions and utility of visual skills in education.

Visual learning includes all of the activities a student may use to employ visual skills in studying. This is closely related to visual study skills, and these two terms will often be used interchangeably. Visual learning has a well-established definition in the educational literature (Azer 2013, Estevez et al. 2010, Fernandez et al. 2011, Lufler et al. 2012, Nelson 2004).

Some additional terms are used frequently in this research, and may need a definition for consistency. These terms have widely recognized definitions, but other authors may use them slightly differently, so I will define each of the following as they are used in this research.

Active learning is any study approach in which the student physically creates something (Drapkin et al. 2015, Pickering 2014, Sweeney et al. 2014, for examples of active learning in anatomy). Active learning can include writing, making a chart, drawing, or modeling. Discussions with other students or instructors can also be considered active learning. Some sources (LCME 2015) require students to create their own learning objectives for an activity to be considered 'active,' but that definition is not used here.

Passive learning is any study approach that does not produce a physical artifact. Passive learning primarily consists of reading or listening to lectures. Rote copying may also be considered passive learning because it does not engage a student's higher cognitive faculties. These definitions of active and passive learning focus on the physical product made by a student for the sake of simplicity. In reality, the main difference between these approaches the level of mental engagement a student has during the learning activity; however, measuring mental engagement is difficult, while measuring products made by students is easy. Therefore, production of a physical product is used a proxy for the level of student engagement (Prince 2004 for a meta-analysis of active learning literature, Griffith 2015 for a primary school example, Meyers and Jones 1993 and Silberman 1993 for some early examples of active learning research).

Superficial learning is focused on reproducing results, and is often used by novice students who are grade oriented (Marton and Saljo 1976, Biggs et al. 2001, Young 2005, Billett 2001, Pandey and Zimitat 2007, Ramberg and Karlgren 1998). This approach leads students to focus on memorizing content in anticipation of examinations.

Deep Learning is a learning approach focused on understanding content and making connections to existing knowledge. This approach is often used by students with more experience studying, and tends to lead to greater long-term retention (Marton and Saljo 1976, Biggs et al. 2001, Young 2005, Billett 2001, Karjcik and Blumenfeld 2006).

Metacognition is a conscious awareness of one's own understanding of a topic (Biggs 1988, Bransford et al. 2000, Bjork et al. 2013, Flavell 1979, Hacker et al. 1998, Kamp et al. 2015, Kornell and Bjork 2007, Metcalfe 2008, Vadhan and Stander 1994, Zohar and Barzilai 2013). Students new to college often lack the study skills and self-reflective skills to regulate their own learning, they "don't know what they don't know;" a definitive lack of metacognition (Bransford et al. 2000). Further, these novice students (as defined by Bransford et al.) are often unaware of even the *concept* of metacognition, and are therefore, not only unable to regulate their own learning, but are lacking the tools necessary to understand self-regulation (Bransford et al. 2000). Many students are able to 'trick' themselves into thinking they know more than they actually do. A lack of metacognitive skills makes self-regulation of learning nearly impossible, and students may study inefficiently and approach exams with undue confidence (Kruger and Dunning 1999).

Dissertation Research Outline

Unless one had abundant resources and an endless pool of volunteers, no single study could effectively address the three main components listed above (guided by the eight research questions described in chapter 3). Multiple different studies (entitled "facets", below) were needed to examine each of the following research questions (for a detailed breakdown of the research questions see chapter 3, subheading "Research questions"). Sometimes, one study or facet could address multiple research questions. Thus, depending on the research question, one or more studies (facets) may provide evidence for the question. Table 1.1 provides a visual for how the facets of this dissertation research map to the research questions:

Facet	Populations Examined (Chapter 3)	Main Research Question (Chapter 3)	Subordinate Research questions	Chapter
1. Study Skills Survey	A215 P215 A550 P531	What study methods do students use?		4
2. Visual study skills	A215	Do students use visual study methods?	Does the use of visual studying change during the course?	5
3. Mental Rotation	A215	How much spatial ability do students have?	Does spatial ability change during the course?	6
4. In-Class Drawing	A215	Does the use of in-class drawing lessons improve SA or VL?		7
5. Web-based video tutorials	Various	Does the use of web-based drawing tutorials improve SA or VL?		8

Table 1.1- The relationship between research questions and the individual facets of the larger research plan.

The first facet of this dissertation research (entitled “what study methods do students use?“) examined the basic methods students use to study. A survey (see survey design in Appendix A) was developed which asks students to report how frequently they engaged in a variety of study habits while studying for courses. This survey was given to undergraduates in anatomy, undergraduates in physiology, first-year medical students (MS1) in anatomy, and MS1s in physiology. All students surveyed were on the campus of Indiana University, Bloomington. A four-way comparison was then conducted to look for differences in study approaches in the two different classes at two different levels. Some of these data were previously reported in Husmann et al. 2016. Husmann et al. examined the changes in study skills exhibited by individual students between their different classes. The analysis of changing study skills is not part of this dissertation. The correlations of study skills with grades reported in this dissertation have also been presented as a poster at the Experimental Biology national meeting 2011 (Husmann and Barger 2011). The detailed methodology, results and discussion of this facet may be found in chapter 4 of this dissertation.

The next facet of this dissertation research (entitled: “visual study skills”) involved a more refined survey (Survey Appendix A), which included more specific questions dealing with visual approaches to studying. This survey was given only to undergraduates, due to the relatively small number of medical students available for research (n = 36). Additionally, a mental rotation test (MRT) was developed by modifying the work of Bodner and Guay (1997). The MRT functions as a measure of students’ ability to mentally manipulate two-dimensional representations of three-dimensional objects. This ability is necessary in anatomy, and a student’s MRT scores have been shown to correlate with success in visually oriented science courses (Keehner et al. 2006, among many others detailed in the literature review). Preliminary versions of the results found in chapter 5 were also presented at the Experimental Biology national meeting 2012 (Barger 2012). The detailed methodology, results and discussion of this facet may be found in chapters 5-6 of this dissertation

Having established a baseline of student performance and visual skills, the third part of this dissertation research introduced a pedagogical intervention designed to improve student MRT scores, visual approaches to studying, and course success metrics. This intervention consisted of teaching students how to draw specific anatomical structures, while learning the normal anatomy course content, during regular lectures. The instructor led the students through guided drawings of anatomical structures, while explaining their functions and relationships. Students involved in this intervention showed small improvements in the above measures, but none of the changes reached statistical significance. Preliminary versions of the results found in chapter 7 were also presented at the Experimental Biology national meeting 2013 (Barger and Husmann 2013). The detailed methodology, results and discussion of this facet may be found in chapter 7 of this dissertation.

In an effort to increase student exposure to anatomical drawing, the next facet of this research moved all of the experimental materials (surveys, MRT, and drawings) to an online environment, with the goal of delivering more drawing practice to busy students. The online drawings were part of a software tool called *Draw It to Know It.* This software was developed by a neurologist (and former IU student) who was unconnected to the research (Draw it to know it 2016). This phase of the research showed that a proportion of students are resistant to visual learning, an expected, but disappointing finding. However, even among students who reported a distaste for visual learning in general (and drawing specifically) they reported understanding the necessity of learning how to use images in their studying. The detailed methodology, results and discussion of this facet may be found in chapter 8 of this dissertation.

All of these pieces, taken as a whole, show the need for increased instruction in visual skills for anatomy students. Many students enter college (or medical school) with inadequate visual learning skills, do not necessarily understand the utility of visual communication, and have no way of improving these skills without specific instruction. The following chapters will explain each of these facets in greater detail, with a final summary detailing the pedagogical implications for anatomy instructors.

General arrangement of the dissertation

The following chapters in this dissertation are arranged around the research questions and individual projects defined in Table 1.1 (above), starting with chapter four. Preceding the individual projects chapters, chapter 2 is a summary and discussion of the existing publications related to visual literacy and spatial ability. Chapter 2 is subdivided in specific sections dealing with visual literacy (with specific examples from many of the disciplines to have researched the teaching of visual literacy) and spatial ability (again with a discipline specific organization of the literature). Chapter 3 outlines the research questions guiding the research conducted in chapter 4-8. Chapter 4 reports the detailed methodology, survey, and student populations used to establish the baseline of student study habits followed by results. Chapter 5 contains detailed methodology, survey, and student populations used to research the visual literacy of anatomy undergraduates, with results. Chapter 6 introduces a measurement of spatial ability, and contains the detailed methodology of measuring spatial ability in anatomy undergraduates, with results correlating spatial ability with a variety of other measures of success in an anatomy course. Chapter 7 introduces a pedagogical intervention (in-class drawings) designed to teach spatial ability and visual literacy, and compares an experimental and control group in measures of spatial ability, visual literacy, and course grades. Chapter 8 uses a similar pedagogical intervention to that in chapter 7, but the drawings are delivered through a web-based series of video tutorials. Chapter 8 contains detailed methodology and results, comparing use of the web-based tutorials to mental rotation score, visual literacy, and other study skills. Chapter 9 is a detailed discussion, summarizing the results of the previous chapters, relating the research of this dissertation to the exiting literature, and discussing limitations of the current research. Following chapter 9 are a series of appendices including the surveys used, the statistical validation of the surveys, the mental rotation test used, IRB approval numbers, IRB informed consent documents (also called ‘study information sheets’), IRB recruitment documents, and syllabuses from courses surveyed.

CHAPTER 2: Visual Literacy and Spatial Ability in Educational Research

All four branches of the anatomical sciences (gross anatomy, neuroanatomy, embryology and histology) share the properties of visual identification, understanding of structure/function relationships, and understanding the relationships and interconnections of all the parts of the body. To be successful in anatomy courses, a student needs a strong set of visual-spatial skills, due the importance of visual identification of structures in anatomy courses. To be successful in visual identification, a student must be able to apply a variety of visual skills. These skills include visual literacy, spatial ability, and mental rotation. *Visual literacy (VL)* is the skill of interpreting visual images (Avgerinou and Ericson 1997, Fransecky and Debes 1977). This skill includes interpreting drawings of anatomical structures, three-dimensional models, and charts or graphs. While this short definition of VL seems simple, it contains a long and complicated history which will be discussed in the following section.

Another term occasionally seen in the literature is *pattern recognition.* This term is most frequently associated with foreign language learners (Martinez-Trinidad and Guzman-Arenas 2001), and computer-based neural networks designed to identify patterns (Carpenter and Grossberg 1988). While this term accurately describes some of the behaviors anatomy experts use in identifying structures and relationships (Berliner 1988), it is used infrequently in publications related to visual literacy pedagogy.

Spatial ability (SA) is the related, but distinct, ability a person has for mentally manipulating three-dimensional mental objects (Linn and Peterson 1985, Linn and Peterson 1986, Lohman 1979). *Mental rotation (MR)* is a specific sub-category of spatial ability, and will be used as a measurement of spatial ability (Bodner and Guay 1997). These three skills (VL, MR, and SA), which I will collectively define as *visual skills (VS)*, are critical for success in all fields of anatomy, and in many other science courses, but are often overlooked by students. Instructors can also overlook the need for visual skills, and it is often assumed that students will begin the course with the relevant background skills, or pick them up during the course, without any specific instruction in improving visual skills (Faurie and Khadra, 2012). (As clarification of the term 'visual skills,' I am unaware of any educational literature that uses this term. When the term 'visual skills' appears in published literature, it is often used as a near synonym for 'visual ability,' that is, the actual functions and processes related to normal human vision. I am using the term 'visual skills' to refer to the mental processes students use to make meaning from images, and not to the functioning of their eyes). Spatial ability and mental rotation will be discussed in the last section of this chapter.

Visual Literacy

Visual literacy (VL) is the ability to meaningfully interpret static and dynamic images, and has a long and contentious history, described in the following pages (Avgerinou and Ericson 1997). Despite the simple, one-line definition for visual literacy given above, it is a complicated and wide-ranging topic that has resisted a firm definition for the last fifty years. Practitioners and researchers in a variety of fields have each applied their own unique definition to this term, making it even harder to reach a consensus definition (Avgerinou and Ericson 1997). Very little has been written about visual literacy in anatomy or biology, so this review will include literature from other fields, including biochemistry, astronomy, and fine arts. Additionally, writings by philosophers and historians of science (Pauwels 2006, Marcaida 2016), sociologists (Grady 2006), and graphic designers (Tufte 1990) will be considered in order to help define the limits and goals of visual literacy. The other gap in the visual literacy literature is in assessment. So much time and effort has been spent in trying to define 'visual literacy' as a term, that few writers have commented on the most effective ways of teaching the actual skills involved in visual literacy. The lack of assessable goals for the visual literacy movement is directly linked to the definition problem, and a major source of concern for educational psychologists (Seels 1994).

Visual literacy was first defined in 1969 by John Debes as "...a group of vision---competencies a human being can develop by seeing and at the same time having and integrating other sensory experiences… when developed they enable a visually literate person to discriminate and interpret visible actions, objects, symbols… Through the creative use of these competencies he is able to communicate with others," (Fransecky and Debes 1972, Avgerinou and Ericson 1997, p. 281.) In the intervening years, most other authors on the subject of visual literacy have modified this definition to best fit their field of study; these will be discussed in greater detail in the discipline specific sections to follow. However, all of the subsequent definitions seem to retain the basic kernel of interpretation of symbols, and visual communication. A full summary of the historical debate concerning VL is beyond the scope of this work, as I will be focusing on the current definitions and applications in use across a variety of fields. For a review of the history of VL see Avgerinou and Ericson (1997).

While I will not be exploring the historical squabbles over semantics in VL, there have been a few interesting arguments made against VL as a term and as a concept. Some authors (e.g., Cassidy and Knowlton 1983, Suhor and Little 1988) have even argued for abandoning the term as a misleading and potentially damaging concept. Suhor and Little (1988) argue that semiotics already encompasses the majority of what is meant by visual literacy, and that education in semiotics is more valuable than creating a new term of visual literacy. While I agree that semiotics and VL have some overlap (discussed in the section on Fine Arts, below) I do not think VL and semiotics are synonymous enough for one concept to replace the other. Cassidy and Knowlton (1983) argue that the term "visual literacy" is used as a scientific metaphor, and that it fails on the principles used to judge other scientific metaphors. However, I find their argument a weak one, because they have applied their own definition to the term "visual literacy" which seems to overlook the goal of the original definition. The definition used by Cassidy and Knowlton (1983) very literally interprets the various meaning of 'visual' and 'literacy' in such a way that "visual literacy" as a separate concept can no longer exist. They also argue that no evidence has been shown that visual literacy can be taught, and that the 'definition problem' (defined earlier) has actually been counterproductive to inquiry in this field. I agree with both of these arguments, but that alone is not enough to destroy the concept of VL. Cassidy and Knowlton do concede the utility of images in communicating complex concepts, but argue that all normal humans are able to communicate with images without any specific training. This is my biggest problem with their argument against VL. Understanding and communicating with non-arbitrary (representational) images is just as complicated as learning to communicate with the arbitrary symbols used to create words and sentences, especially when applying all of the discipline-specific ways of using images (Seels 1994). Since the early 1980s, the arguments against the utility of visual literacy seem to have subsided. The last thirty years have seen tremendous growth in the number of visual images in daily life, and most authors now seem to agree that educating students to critically interpret images has value (Avgerinou and Ericson 1997, Alenn 1994, Glasgow 1994, for a discussion of visual literacy as a tool against pressures of advertising and consumerism and Ainsworth et al. 2011, Dempsey and Betz 2001, Heuschele 1999, Lyon et al. 2013 for a representative sample of the small number of publications to discuss the utility of VL in science). In fact visual literacy has become so widely accepted as a field of inquiry, that a Journal of Visual Literacy was founded in 1989, and still publishes two issues each year. The content of this journal is more abstract and philosophical in nature, and rarely deals with specific disciplines. However, the continued conversation in visual literacy is valuable resource to instructors interested in improving visual literacy in students. The remainder of this chapter will examine the current state of the VL debate, how VL has been taught, and the necessity of teaching VL to novice learners in a variety of fields, including anatomy.

As a direct counterpoint to the arguments against VL as a concept and a field, this section will explore some of the literature focused on attempts to teach VL, and the researchers who have defined the need for VL education.

In people with normal visual acuity, vision is the primary sensory modality mediating the experiences of the world, so understanding the interpretation of visuals is of obvious interest (Avgerinou and Ericson 1997). Additionally, the use of images as communication has only increased in recent years, leading Avgerinou and Ericson (1997) to coin the term "bain d'images," literally a bath of images, an apt description for the prevalence of visual communication in mass media. This constant input of visual communication means that skills must be developed to interpret and analyze these images. Cassidy and Knowlton (1983) might argue at this point that understanding images does not require specific skills, but it is the deeper meaning and fine details of an image that are so often ignored without the use of visual literacy (Sless 1984, Seels 1994). Attempts at introducing visual literacy into school curricula (of all grade levels) go back decades, with varied goals and success rates (Avgerinou and Ericson 1997, Alenn 1994, Glasgow 1994). Many of the earliest attempts to teach VL focused on primary and secondary school students, with the goal of critical analysis of advertising. This skill is one way of teaching VL, and a valuable exercise, but not specifically relevant to teaching anatomy to post-secondary students. Therefore, a following section will summarize recent projects aimed at teaching VL to college undergraduates and professional students in a variety of fields, with the goal of distilling a working definition of VL, and supporting its value as a continued realm of inquiry.

Visual literacy as a concept, construct, cultural resource or measurable phenomenon?

If visual literacy has proven so hard to define, but so resilient as an idea, what kinds of definitions have been attempted? This section is an attempt to summarize some of the most interesting definitions and conceptual schemes that have been applied to the idea of visual literacy. Sless (1983) argues that visual literacy is “a cultural resource, not an experimental result” (p.228). He explains this position by arguing that visual communication has existed for centuries, and current psychological tools are still not able to understand the complex interactions that make this possible. Sless continues to say that there are undeveloped areas of education where visual literacy can be employed, but empirical research should not necessarily be the goal.

Despite the decades of argument and lack of consensus, visual literacy has persisted as an idea and as a term, only becoming more prominent in recent years with the growth of visual communication technology. Even if the term remains difficult to define, the idea of visual literacy has utility in science education that will be examined in the following sections.

While a consensus definition of visual literacy amongst all interested parties may never be possible, the following section will explore recent developments and current plans for the visual literacy idea. A recent group to tackle this problem of defining and assessing VL has been The Association of College and Research Libraries (ACRL) who released a set of standards for VL in October 2011 (Hattwig et al. 2013). With this new, highly versatile, and all-encompassing definition, perhaps future researchers can shift their focus from the "definition problem" to assessing the effectiveness of teaching VL (as mentioned by Perkins 1994). Assessment has still been given short shrift in the ACRL list. Even in the new standard, assessment only merits a few sentences in the twelve-page document. The ACRL opinion of assessing VL competencies is the same as previous authors, and is still a work in progress. This is one goal of this dissertation; to find effective ways of teaching and assessing visual literacy and spatial ability in anatomy students. Despite the assessment weakness, the ACRL standard still has a lot of strengths, in that it cleanly defines seven competencies of VL that have been approached by the previous authors on the subject. The seven competencies are summarized below, as well as how previous authors (in a variety of fields) fit into this new scheme.

The ACRL List of visual literacy competency standards

The ACRL have defined seven competencies or skills that a student must exhibit to be said to be visually literate (Hattwig et al. 2013). These seven skills follow a hierarchical organization similar to Bloom's taxonomy (Anderson et al. 2001), in that the student must first be able to identify a need for visual materials, before moving on to interpreting, evaluating, or creating visual materials. The ACRL seven competency of visual literacy (Hattiwig et al, 2013) are as follows:

1. Determine the nature and extent of the visual materials needed
2. Find and access needed images and visual media effectively and efficiently
3. Interpret and analyze the meanings of images and visual media
4. Evaluate images and their sources
5. Use images and visual media effectively
6. Design and create meaningful images and visual media
7. Understand many of the ethical, legal, social, and economic issues surrounding the creation and use of images and visual media, and access and use visual materials ethically

Each of these competencies are described in detail in the subsequent paragraphs.

Competency 1: Determine the nature and extent of the visual materials needed.

The first competency defined is to determine a need for visual material. This means that a visually literate student can define a need for images in a given context. This specific skill is a widely accepted part of the VL literature, with many authors commenting on the need for restraint in the use of images (Pauwels 2006, Tufte 1990, Trumbo 1999).

Anatomy students find this first skill challenging for two reasons. First, they often miss the utility of an image to convey lecture content. For example, a student may not realize the direct connection between the vocal folds and arytenoid cartilages when this concept is described verbally, but upon seeing an image of this connection, the concept becomes clear. A student with high visual literacy, and an understanding of the need for appropriate images, can find or construct this kind of image from the verbal description, while a student with low VL cannot. The second challenge for anatomy students in using this skill is overuse or over-reliance on images. Over reliance on images shows up most frequently when a student will simply glance at an image, without taking the time to understand the meaning conveyed. This may also be considered as a misuse of the image, but it is related to the above competency in that relying solely on images while ignoring text and context is a common pitfall for the student with underdeveloped visual literacy skills. One of the biggest risks in use of images is making an image too complicated, a frequent problem for introductory anatomy students when using anatomical atlases. The over-complication of images is one of the reasons students fail to fully develop their visual literacy skills. When a novice learner is presented with expert-level visual aids, they can easily feel overwhelmed, and without proper scaffolding in visual literacy training, they may stop using images altogether.

Competency 2: Find and access needed images and visual media effectively and efficiently.

The second competency is the ability to find appropriate images once a need for an image has been defined. Finding images has a place in the larger conversation about visual literacy, but does not play an important role in the use of images for anatomy students. Anatomy students have access to a wide variety of anatomical images in textbooks, lab guides, coloring books, and websites, so assessing and evaluating those images for content and applicability (competencies 3 and 4) becomes much more important.

Competency 3: Interpret and analyze the meanings of images and visual media

The third competency is, in many ways, the core of the original definition of VL. This skill can essentially be rephrased into Debes original definition of "the ability to make meaning from an image" (Fransecky and Debes, 1977). It is interesting that the original definition of VL is now placed at the middle of the hierarchy, indicating that there are even more basic skills needed before a student can begin to make meaning from an image. The fact that there are also more complicated skills, which build on the ability to interpret an image, tells us that reading an image is not the only goal of VL, and many of the early definitions missed a key component of VL. Much like verbal literacy, reading and interpreting a passage is not enough, a student must be able to evaluate, use, and create text to truly have verbal literacy.

For most anatomy students, this skill is where they will spend most of their time. Making meaning from an image is what students do when they study anatomy atlases, and it is also how most student learning is assessed in anatomy laboratory courses. To elaborate, most laboratory examinations are based on the visual identification of an image (histological, photographic, or radiological), a model, or a dissection (for a detailed examination of this topic, see Chapter 9 which explores the role of ‘authentic assessment’ in student learning). If instructors are using visual literacy skills as a major part of assessing student learning, then visual literacy skills must be taught side-by-side with course content. Additionally, making meaning from images is a critical diagnostic skill for physicians (again histology and radiology, specifically), so competency #3 has obvious clinical applications (Murphy et al. 2014).

Competency 4: Evaluate images and their sources.

The fourth competency of evaluating images incorporates several meanings in the idea of evaluation. First, a student must be able to critique the effectiveness of an image; does it convey the intended meaning? What features are missing from this image because of the choices made by the artist? The second definition of evaluation involves the reliability of image sources, an important consideration with web-sourced images, but (hopefully) not one that students will encounter in textbook or lab images.

Evaluating images may be too lofty a goal for most anatomy students, but if this idea can be discussed (even briefly) in a laboratory context, it will lead to students applying more critical thought to their observations. All images are an attempt to communicate, and in any form of communication, choices must be made about what is worth conveying, and how best to do that. If students can be taught to consider the choices made in the construction of an image, they will gain a better understanding of the subject matter.

Competency 5: Use images and visual media effectively.

The fifth competency defines the use of images, but more specifically relates to the use of images to communicate ideas. To meet this competency, a student must be able to do all of the preceding steps, but is now selecting and curating their own images to communicate new ideas. In my personal experience, I have seen this skill used most frequently in histology. Much of a student's time in histology labs is spent scanning through slides on a microscope, and checking with an instructor to ensure the correct cells and tissues have been identified. With new virtual microscope software, students can now view high-resolution scans of traditional microscope slides on a computer, and capture images from the slides (Husmann et al. 2009, Collier et al. 2012, Bruch et al. 2009, Braun and Kearns 2008). Capturing and labeling microscope images is exactly the process of "selecting and curating images to communicate ideas," a clear fit with the fifth competency as defined by the ACRL.

Using images, as defined by the fifth competency, can also relate to a student explaining a concept with an image. For example, if students were given the opportunity to present research findings in a visual way, while explaining the image, that may demonstrate this competency. Additionally, a multiple choice examination question could ask a student to match a concept with the image that illustrates the concept. There is a place for this competency in anatomy education, but the current structure of many anatomy courses (lecture-based with purely verbal multiple-choice exams) may make this idea harder to integrate in the classroom or laboratory. Of course, this competency is frequently modeled by instructors who will often use and explain images in lectures. A short description by the instructor to make explicit that the lecture is a model of a type of visual literacy, could help students understand this competency. If students are then encouraged to use this behavior during their own study time, by writing explanations of images, or using images to describe concepts to peers, this competency can easily be taught.

Competency 6: Design and create meaningful images and visual media.

The sixth competency has the students creating their own, new images. Much like in (some revisions of) Bloom's taxonomy, creation is the highest goal of the truly successful student (Anderson et al. 2001). In the ACRL scheme, the creation of appropriate, meaningful, and necessary images will best be understood once a student has exposure to all of the components that unite to form a good image. In anatomy, creation of images is often suggested by instructors, but without the appropriate scaffolding of the lower levels of visual literacy. Producing images to convey meaning is a challenging goal. For students to begin making meaningful images, they must first be instructed in the lower levels of image understanding. The lower levels are easy to overlook, especially in a content-based course where visual instruction is an afterthought. Much of the content in following chapters will deal with different instructional interventions designed to instruct anatomy students in image creation.

Competency 7: Understand many of the ethical, legal, social, and economic issues surrounding the creation and use of images and visual media, and access and use visual materials ethically

The seventh competency lies somewhat outside the context of communicating with images, and focuses on the ethical and cultural practices associated with images. This is an important idea, but not one that has been discussed much in previous literature. Publications dealing with the ethics of body donation are quite common (Champney 2016, Fonseca 2016, Winkleman et al. 2016), including several recently published articles detailing 'best practices' for maintaining transparent and ethical body donation programs (Jones 2016, Riederer 2016, Schmitt 2014). However, few of these papers deal explicitly with the ethical questions of producing images from donated specimens (exceptions include Cornwall 2016, Cornwall et al. 2016). Issues such as ethical production and acquisition of images can be important for artists and publishers, but rarely appears in the science literature. Many, maybe all, images used in human anatomy are based on human specimens. This has obvious ethical implications when an image is a photograph of a human cadaver (Jones et al. 2003, Barilan 2005, Barilan 2006, Cornwall et al. 2016). Human remains willed to schools as a part of a body donation program are subject to guidelines and informed consent documents, but no specific legal protections exist in all jurisdictions (body donation ethics being an international concern) (Jones 2016). The guidelines and consent documents provided to body donors frequently include a limited period of use (Jones 2016), but a photograph of a body may violate the terms of use. Additionally, body donors may be unaware of the possibility of their remains being subject to a permanent photographic record, and may be uncomfortable with that possibility, especially when images of body tissues are not considered in the original donation documents. The wishes of the body donor must be considered to ensure ethical production of images (Jones 2016). A new study also discusses the ethics of 3D printing of anatomical models based on actual human remains (Cornwall 2016). Three-dimensional printing is a new technology for producing 3D images (models) that has only recently been explored for the making of anatomical images, and the ethics of this practice will doubtless become a productive area of discussion in the coming years (McMenamin et al. 2014). Less obvious are the ethical implications of drawings based on human remains. Information is produced in the creation of the image, but if that image is based on human remains that have been obtained through morally or legally dubious means, what are the responsibilities of the instructor or student who uses that image? Recent works have seemingly rediscovered the anatomical contributions of Nazi scientists working with human specimens from concentration camps (Atlas 2001, Panush 1996). Is the use of these images ethical? I am not an ethicist, and cannot answer that question, but see (Atlas 2001, Hildebrandt 2016, Jones 2016) for a discussion of the various ethical arguments arising from this material. Additionally, the use of microscope slides containing human tissue can be an ethical briar patch. Often, the provenance of the tissue in microscope slides is uncertain at best, and the user of the slide cannot be certain the donor gave consent for his or her tissue to be used in perpetuity (Jones et al. 2003). These ethical questions form a fascinating and critical part of image use in anatomy, but are outside the scope of the current research.

Having defined visual literacy through a series of competencies, the following sections will focus on the application of visual literacy research in a variety of academic fields. Fine Arts research will be considered first, with design and sciences following.

Visual literacy in Fine Arts

The field of Fine Arts has understandably spent a lot of time defining visual literacy. Much of the arguing about specific definitions of the term comes from educators in the Fine Arts. There is still no consensus amongst arts educators, but several good discussions have been published in the arts literature in the last four decades (Yenawine 1997, Raney 1999, Kemp 2006, Rourke and O'Connor 2010). Much of the VL literature in Fine Arts has focused on using the rules of art and composition to understand the process of making an image (Dondis 1973, Perkins 1994). While this is visual literacy in that the art instructor is using images to create meaning, the meanings are about the image itself, as opposed to what the image is about (see the following paragraph on semiotics [p. 37] for a discussion of terms ‘sign’ and ‘signified’ which relate to the various types of meaning an image can have) .

In contrast, the VL literature from science is primarily concerned with conveying meaning about a specific topic using an image, not understanding the construction of the image (specific examples in the relevant sections). Even so, the definitions and principles used in VL in the Fine Arts can form valuable background information for the discussion of VL in science. The difference between the content of the image and the construction of the image itself has been exhaustively discussed in the literature of semiotics, using the terms ‘sign’ and ‘signified’ to denote the image and its contents respectively. When discussing images, a variety of different terms have been used with similar and overlapping meanings. Another specific term that reoccurs is the ‘external representation.’ This terminology has been used a cover term that includes all manner of visuals, images, charts, models, and graphs. This term has specific utility when contrasting internal visualizations (i.e., mental images) and external visualizations (e.g., a drawing on paper).

All external representations are made of the same fundamental elements as defined in *A Primer on Visual Literacy* (Dondis, 1973). The author defines these elements as analogous to an alphabet for verbal literacy, and then uses these building blocks to construct an entire visual/verbal literacy metaphor, which goes on to clearly teaches a student of the visual arts how to make meaning of an image. The visual/verbal metaphor begins by defining literacy as “a group [sharing] the assigned meaning of a common body of information” (p. x of preface), a valuable starting point for the discussion of literacy. However, there is no discussion of using images to convey content about abstract ideas, or how to assess the acquisition of visual literacy skills in students. This gap in assessment may be due to the time period in which the book was published. In the early 1970s workers in visual literacy were still struggling to agree on the goals of a visual literacy movement, assuming assessment and measurement questions would be answered in the future (Perkins 1994 and Wiles 2016 also mention the need for assessment of VL as a future goal). The greatest strength of this book in the explicit definition of the six visual design elements that everyone subconsciously decodes when looking at an image: line, color, shape, texture, space, and form. Dondis also warns against ‘over defining’ visual literacy (p. 9), saying that the natural and instantaneous ability for humans to recognize images is a strength of visual literacy, and that forcing too many restrictions on the concept weakens it. Dondis also makes the claim that vision, while natural, takes great practice to use efficiently and effectively, a claim supported by many later authors (Seels 1994, Allen 1994, Glasgow 1994, Mayer 2014), ignored but Cassidy and Knowlton (1983), and renamed by Suhor and Little (1993).

The literature of visual arts (Fine Arts, graphic design, industrial design, and others) is filled with discussion of the interplay between these six elements, and how they can be used by an artist to build an image (Kemp 2006). Understanding how to build an image is of obvious necessity to a visual artist, but it tells us little about how these elements can be deconstructed from a scientific photograph or illustration. For a discussion of the use of these principles in an identification-heavy field, the field of textile and interior design has some interesting things to say. Rourke and O'Connor (2010), both visual artists and designers, have used these elements of design to teach students how to identify the work of specific designers. By identifying the typical use of color and pattern, a naïve student can take a novel piece of industrial design and identify the designer. This is very similar to the process by which a student will identify a specific tissue in a histology course. So, the understanding of the elements or principles of visual arts will help a student create a background to begin decoding the information within an image.

Another valuable definition to come from the Fine Arts is the idea of "seeing as cultural habit" (Raney 1999). The cultural background and experience of a person directly effects what they see, so an expert and a novice in a field will make completely different meanings from the same image. This idea will become crucial in teaching novice learners in anatomy; a lot of the instruction in labs is a tacit process of acculturation to be able to see like an expert.

Art historians have also used visual literacy principles to understand the ways different cultures and different time periods have produced images. A quote from

Wolfflin (1950) will help to illustrate this idea; “not everything is possible at all times” (p. 11). This reminds us that art history is a gradual process of different cultures and time periods acquiring new conventions for the creation of images (as reiterated by Francey et al. 1996). To understand why and how a specific culture or time period uses images requires visual literacy. By ‘reading’ the alphabet of the image - to use the metaphor of Dondis (1973) – art historians can understand the cultural conventions that produced the image and place the image in context. Art history research has also provided another piece of the definition of visual literacy; by making clear the separation of the visual and the verbal (Gombrich 2000). Gombrich defines the unique place of visuals by noting that visual representations of reality have “fidelity” to reality that words never do. He goes on to state that visuals may be more or less faithful to reality to convey different meanings, but a word is always a word with a set meaning. Of course context plays a role in defining a word, but image context is equally important as seen above.

Having defined some of the limits of visual literacy through the work of artists and art historians, the next section will apply these principles to the sciences. Biochemistry will be discussed first, followed by a section summarizing VL as it applies to anatomy.

Visual literacy in biochemistry

This section discusses pure visual literacy (that is, the interpretation of an image) and is not directly related to spatial ability (mental manipulation of 3D images). Many scientific fields have examined spatial ability, but pure visual literacy research in science education is less common.

Biochemistry educational researchers have done the most work with VL of any of the sciences (Schonborn and Anderson 2006, Anderson 2007, Schonborn and Anderson 2010, Wiles 2016, Serpente 2016, Linenberger and Bretz 2015). This may be due to the necessity of creating meaningful mental representations of biochemical entities in the study of biochemistry. Biochemical entities are mostly molecules and proteins, impossible to actually visualize with a microscope, so conceptual visual models are the only visual representations available to student of biochemistry. The variety of representational schemes for biochemical entities is also mentioned as a need for robust VL education in biochemistry (Wiles 2016). That is, a protein, for example, can be represented by a linear arrangement of letters corresponding to amino acids, a 3D ball-and-stick model, or a 3D ribbon diagram. Each of these visual representations of the protein conveys different information, and the biochemistry expert is able to extract the information of the image, and even infer the appearance of one type of image from another type of image (Schonborn and Anderson 2006). The publications in biochemistry have been particularly valuable in defining the facets of VL that most directly relate to anatomy. One group of biochemistry pedagogy researchers have defined a unique set of factors that are directly related to how students interpret images and visualize concepts (Schonborn and Anderson 2010). In this scheme, there are three major factors influencing VL; 1) conceptual knowledge of the information in the image, 2) reasoning ability with respect to images, and 3) representation mode of the image itself. These three factors use different names, but are largely in line with the skills defined by the ACRL, and VL definitions from the fine arts. Though the terms used in biochemistry may have more use in VL of sciences, the definitions are still not perfect, and introduce some ambiguity where other authors have been more precise (Schonborn and Anderson 2006, Moore and Dwyer 1994).

The biochemistry definitions add the conceptual knowledge component, which is ignored in so much of the arts literature because of the focus on the image itself, as opposed to its content. The conceptual knowledge element is an important consideration when using an image to communicate information about a specific topic, rather than the image itself.

The second component from Schonborn and Anderson (2010) is the reasoning ability with respect to images. Reasoning ability encompasses the entire "repertoire of skills" a student brings to the interpretation of an image. The definition of "reasoning" used here is a bit ambiguous with respect to the ACRL standards, because Schonborn and Anderson have grouped a huge variety of skills with different cognitive bases together under one single umbrella term. The list of skills involved in reasoning with images includes:

- Decode the symbolic language composing an image
- Evaluate the power, limitations, and quality of an image
- Interpret and use an image to solve a problem
- Spatially manipulate an image to interpret and explain a concept
- Construct an image to explain a concept or solve a problem
- Translate horizontally across multiple images of a concept
- Translate vertically between images that depict various levels

of organization and complexity

- Visualize orders of magnitude, relative size, and scale.

This list incorporates decoding, interpreting, evaluating, and constructing images, grouped together as a single skill, while the ACRL defines each of these as individual skills. Additionally, this list explicitly defines the need understand scale, and the ability to use multiple images with different scales and representation modes, crucial factors in scientific visual literacy. This list also includes spatial manipulation, which will be treated separately in a following chapter.

The final part of the Schonborn and Anderson VL scheme (2010) is the representation mode of the image. An image must clearly convey the desired information in a meaningful, and some modes are more appropriate for specific applications. For example a protein can be visually represented by a ball-and-stick chemical model or a space-filing model, depending on the ideas the instructor wishes to present. Each mode of presentation has value, and each highlights different aspects of the protein. The mode of presentation interacts with the conceptual knowledge and reasoning ability of the viewer to produce visual literacy.

Visual literacy in astronomy

Only one paper has been published on the visual literacy of astronomy students (Crider 2016). The author is an instructor of undergraduate astronomy students, and uses the ACRL scheme for teaching visual literacy as a way of understanding astronomy. The author does not use any specific visual literacy assessments, but rather uses the 'Moon Landing Hoax' as a case study for the utility of good visuals in science, and the understanding of those images as a bulwark against bad information from 'edutainment products.' (p. 17). This research points to the utility of visuals in communication, especially for eliminating deep-seated misconceptions, like the 'Moon Landing Hoax.' While there is no explicit assessment of students learning of VL, the author does say that strong visual literacy skills, especially in understanding how images are made, and in making one's own images, can help students understand misconceptions about science.

Visual literacy in anatomy

In the anatomical education literature, spatial ability research is common (see below), but visual literacy discussions are rare. The few examples of VL research in anatomy education (Backhouse et al. 2016, Bardes et al. 2001, Bell et al. 2014, Pickering 2014) are explained in the next paragraph.

Backhouse et al. 2016 used an in-class drawing exercise with anatomy first-year medical students to teach anatomy content and VL skills at the same time. They found that using drawing (combined with reflection and editing) as an in-class activity led to lower exam performance, despite positive perceptions of the drawing exercises. When the drawing protocol was moved to an optional tutor-led environment, exam scores improved significantly. Additionally, students who self-reported liking to draw did not differ from students who disliked drawing in any of the measured variables.

Pickering 2014 used a computer animation (with narration and a student drawing component) to teach anatomy to medical students. The paper deals with visual literacy as related to working memory and cognitive load, and shows that computer based drawing lessons correlate well with evidence-based best practices in medical education. Bell and Evans 2014 and Bardes et al. 2001 both used observation training with of works of art to improve the clinical observation skills of medical students. Both papers report a high degree of student satisfaction with the program, and an increase in observational skills. Observational skills were measured by a panel of experts, and the number and detail of clinical observation increased in the study populations.

What does the visual literacy research in the other fields mean for anatomy?

Having defined VL across multiple fields, each with its strengths and weaknesses, what can we say about the visual literacy skills needed by an anatomy student? Which specific competencies are most important? I define here a list of visual literacy skills that are most important to anatomy students. This list is based on the definitions and studies reviewed in the previous pages. The following table uses the ACRL list of visual literacy competencies as its base, but includes some of the specific skills defined by the work of biochemistry educational researchers.

Primary visual literacy skills needed by anatomy students	**Competencies included in each primary skill**
1. Interpret and analyze the meanings of images	a. Decode the conventions and design elements used in anatomical illustration b. Understand the scale of the image c. Compare two images of the same object presented in different modes d. Compare two images of the same object from different angles
2. Evaluate images for their strengths and weaknesses	a. This should include textbook photographs, illustrations, and medical imaging
3. (Use existing images and visual media to communicate effectively)	a. Rarely do anatomy students (in the sample populations) have the opportunity to use images to communicate
4. (Design and create meaningful images and visual media)	a. Image creation is the highest goal of visual literacy and may not be practical to teach the conventions of image creation in anatomy courses

Table 2.1- A list of the visual literacy skills anatomy students need to learn from images and effectively communicate with images, as prepared by the dissertation author. Skills 3 and 4 are enclosed in parentheses because they are goals of visual literacy education, but may be outside the scope of most anatomy courses.

Most of the time spent working with images in anatomy focuses on the first two skills defined here. That is, students will need to interpret images, and evaluate their quality. For example, a textbook image of the heart can be a photograph of a human cadaver, a model organism (like a pig), a realistic drawing, or a diagrammatic drawing. The student studying the heart will need to make several interpretations about the image presented. First, the medium of presentation will give the student some information. If it is a photograph, it is a realistic representation of *one* heart, that is, it may exhibit abnormalities or idiosyncrasies not seen in all specimens. If the image is a drawing, the student must be aware that it is a generalization, and variations exist in the real world. Additionally, the student must consider the choices the artist made in the rendering of the heart image. Why are veins blue? Are the great vessels shown intact or cut? Is the relationship to the rest of the thorax presented? All of these questions subconsciously form the learning that is taking place when looking at an image. This is interpretation and evaluation.

Images outside of textbooks require an additional level of evaluation. The source must be evaluated for accuracy, and relevance. Anatomical images found through Google image search may contain errors, nomenclature variations, or overwhelming details, all of which can hinder student learning. The student must be aware of the mental process of image evaluation to successfully navigate the sea of images.

Students are rarely given the opportunity to use or create their own images for communication in the subject, so skills 3 and 4 are listed as potential goals of visual literacy education, but goals which may be outside the scope of most anatomy courses.

The research presented in chapter 7 details a plan where VL skills are taught to anatomy students as a means of learning course content and VL at the same time, the best way to teach VL according to college librarians who have researched the problem (Nelson 2004).

Spatial Ability

Spatial ability (SA) is distinct from visual literacy in that involves the ability to mentally manipulate, and gain information from, two- and three- dimensional images (Bodner and Guay 1997, Meneghetti et al. 2011). As a specific set of skills, SA has been well defined, and literature dealing with SA has shown more concrete results than the VL literature (examples cited below). That is, spatial ability can be trained and measured . This effect has been demonstrated many time, for example: Lord 1985, Orion et al. 1997, Titus and Horsman 2009, Keehner et al. 2006, Provo et al. 2002, Lufler et al. 2012, Luursema et al. 2008, Boudreau et al. 2008, Hegarty et al. 2009, Wanzel et al. 2002, Fuks et al. 2009, Garg et al. 2001, Nicholson et al. 2016, Canty et al. 2015. Spatial ability can be assessed through a variety of tools, including polyhedral net folding, aperture passing, and cube counting. Each of these spatial ability tasks uses some amount of mental rotation, so mental rotation is frequently used as a measure of spatial ability as a whole (Meneghetti et al. 2016). Spatial ability uses many other mental processes besides mental rotation, but the spatial ability literature seems to agree that mental rotation is a good proxy for measuring all facets of spatial ability (Uttal et al. 2013 for a meta-analysis of the transferability of mental rotation skills to other spatial tasks).

Spatial ability has been well studied in a variety of populations, including anatomy students. In the following paragraphs, I examine the role of gender in spatial ability, and then I summarize the spatial ability studies in both non-anatomical and anatomic fields.

Does Gender play a role in spatial ability skills?

One of the oldest questions in the spatial ability literature is the role of sex (or gender, the terms are not always used consistently) in performance of spatial ability tasks (Hyde 2016 for a history of gender in cognitive science). Cognitive science has shown men and women to be equal in nearly all cognitive tasks, with the exception of spatial ability (Hyde 2016, Moe 2016, Voyer et al. 1995). Hypotheses to explain these differences can be broadly divided into biological explanations (e.g., hormonal or brain organization explanations) or social explanations (e.g., perceptions of gender roles for men and women, spatially oriented hobbies, or attitude) (Quaiser-Pohl et al. 2016, Williams and Meck 1991). In the mid-1990s, two meta-analyses of gender in spatial ability were published, one indicating a decrease in gender differences over time (Voyer 1995), and the other indicating that gender differences have remained stable over time (Masters and Sanders 1993).

Since then, dozens more studies about the role of gender (or sex) in spatial ability have been published (e.g, Barnett-Cowan et al. 2010, Dabbs et al. 1998, Feng et al. 2007, Hausmann et al. 2000, Kennedy and Raz 2005, Langlois et al. 2013, Lawton 1994, Moe 2016, Moffat et al. 1998, Quaiser-Pohl 2016, Xiong et al. 2016), and still no consensus has been reached. Quaiser-Pohl et al. (2016) examined the role of salivary gonadal hormone levels in the performance of mental rotation tasks in children aged 9-14. They found boys performed the mental rotation tasks *faster*, but *no more accurately* than the girls in the sample. Additionally there was no correlation between hormone levels and mental rotation performance. Gradl-Dietsch et al. (2016) examined the role of gender and learning style in the learning of spatial ability in medical students in anatomy. They found no gender differences in the spatial ability tasks, or anatomy learning tasks. While there is still an active discussion about the role of gender (or sex) in training spatial ability skills, these two recent examples, one with children in a pure mental rotation test (Quaiser-Pohl et al. 2016), and one with adult learners in anatomy (Gradl-Dietsch et al. 2016), indicate that men and women are equally good at spatial ability skills. Other recent papers also support the idea that gender differences in spatial ability are minimal at best, and women are equally amenable to the training effects spatial ability instruction (Meneghetti et al. 2016). For this reason, men and women are treated as a single group in this dissertation research.

SA in fields other than anatomy

The SA literature is full of experiments designed to test this ability in a variety of populations. This section will summarize a number of these experiments in fields other than anatomy. These experiments will then be compared those done in anatomy to look for consistency, and draw conclusions about what SA means when learning anatomy. This section also examines the SA literature where researchers have simply compared a student's baseline SA with performance on a variety of tasks. These articles will also provide meaningful background in the ways that SA influences learning.

One of the earliest studies to examine SA in students and use an intervention to improve SA comes from Lord (1985). At the time of his writing, there was still an active debate about the possibility of teaching SA. Some researchers argued that SA was an innate ability which could not be improved (Carp and Silberman 1969, Culver and Dunham 1969), while others claimed that environmental interactions teach SA (McGee 1979). The research presented by Lord used weekly interventions in which college undergraduates in biology courses mentally bisected 3D figures, and drew the resulting 2D image on a paper. His results show that the students in the weekly intervention performed better on an SA posttest than a control group. This result lends support to the idea that teaching SA is possible.

Since 1985, teaching spatial ability has become the norm, with no publications since arguing for a purely innate spatial ability skill. Many researchers have shown the effectiveness of teaching spatial ability across multiple populations with a variety of different pedagogical interventions. The following sections provide a detailed summary of the SA teaching literature of the intervening thirty years. The following sections do not use a historiographic approach to the SA literature, but are rather divided into discipline specific sections, to better understand the unique needs of each discipline, and explore how each of them may be relevant to the teaching of anatomy.

Spatial ability in geology

The field of geology has had an active group of SA researchers for many years, all emphasizing the importance of SA for all levels of geology students and practitioners. Researchers in geology have used mental rotation as a measure of SA, but they also add a unique SA assessment technique in internal visualization. This is the skill required to visualize how the external features of a rock or mountain influence the internal structures. So far, this appears to be a skill unique to the geology literature, but it has obvious uses in anatomy, and is worth future exploration.

In 1996, Kali and Orion published a paper detailing a new method for assessing SA in secondary students of geology. In this test, students were asked to visualize the internal structures of a rock that would be revealed by slicing the rock along a given line. The students who at least attempted to visualize the internal parts of structures, even when wrong, did much better in geology courses overall. They concluded that geology students need to be given specific instruction in SA, including working with models that allow the visualization of layers and internal structures. The authors continued by saying that other sciences with a similar SA need should be identified, and these students should also be offered SA training. Anatomy would certainly fit in this category, but it appears that none of these suggestions have yet been widely implemented, and this article seems infrequently read (or at least cited) outside the geology literature.

Several studies have demonstrated that studying a visually challenging science such as geology will lead to improvements in SA, even without specific instruction or testing in SA (Orion et al. 1997, Titus and Horsman 2009). Orion et al. (1997) showed a reciprocal relationship between the acquisition of SA and geology skills. Learning a visual science or specific SA skills will lead to improvements in the other, and learning both at once will maximize the gains students make (Orion et al. 1997). Titus and Horsman (2009) demonstrated a passive acquisition of SA just by taking a geology course. They assessed SA in geology students at the beginning and end of an introductory geology course, and found significant improvements in SA, even without any specific lessons designed to teach SA to the students.

Piburn et al. (2005) used a computer based interactive animation of geological processes to aid geology undergraduate learning. They found that the novel tool improved acquisition of geology knowledge, and some measures of spatial ability. Additionally, the authors demonstrated that training in SA was able to eliminate differences in geology content acquisition and SA between genders. This shows that explicit training in SA can reinforce content knowledge, while simultaneously improving SA, and can help lower-performing students to meet their peers in visually-oriented science courses. The animations used in this study illustrated two- and three-dimensional views of geological processes, and included visualizations of the interior feature of the earth's crust. The control group did not receive any explicit visualization or SA training. The results of this study indicate that *some* training in SA is beneficial, but they do not make any claims about the efficacy of the specific animations used. It may be that other types of SA training are equally valuable.

Spatial ability in chemistry

Chemistry is another visually oriented science in which students must be able to visualize the shape and orientation of the atoms in a molecule to predict their behavior in reactions. Because there are no photographs that show a molecule as a "ball-and-stick" model, chemistry instructors have to rely on illustrations and metaphors, but the resulting ways of teaching SA are very similar to more macroscopic sciences (Boz and Boz 2008, Ferk and Yrtacnik 2003).

Virtual 3D environments have been shown to help students learn chemistry and improve SA (Trindade et al. 2002). The authors of this study taught chemistry concepts to first-year undergraduates using a three-dimensional image rendered on a flat computer screen, as well as stereoscopic 3D images with a virtual reality rendering environment. The results indicate that 3D visualizations are good at helping students learn, but flat-screen rendering is as good as stereoscopic rendering. Additionally, these benefits in student learning seemed to be confined to those students who were already good at SA. They found no improvement in students' SA scores which contradicts Piburn et al. (2005) results in geology students' use of 3D visualization software. Both studies (Trindade et al. 2002 and Piburn et al. 2005) agree that 3D visualizations can help students learn content, but they reach different conclusions about the utility of teaching students SA skills.

As early as 1983, Small and Morton demonstrated that training undergraduates in spatial-visual skills (their term for spatial ability) improved scores in an organic chemistry class. The students only showed improvement on exam items directly related to 3D visualization of structures, indicating that SA training helps in some specific parts of chemistry learning, but is not widely applicable to all types of questions. Additionally, these students were given SA assessments at the beginning of the course to control for their previous spatial ability experiences, but no post-course SA assessments were conducted, perhaps due to the innate theory of SA which was still common at that time (Lord 1985).

Carter et al. 1987 and Pribyl and Bodner 1987 used SA a predictor of success in chemistry, also apparently working from the innate theory of SA, and finding a correlation between SA and chemistry performance, but did not investigate the interaction between these two variables, or examine possible causal relationships. Neither of these 1987 studies explicitly attempted to teach SA, but only used it as a predictor of success in undergraduate chemistry courses. The teaching of SA as a specific skill did not really enter specific science disciplines until the 1990s as seen in the following paragraphs.

Barke (1993) found that training middle school students in the spatial visualization tasks related to chemistry improved both their knowledge of chemistry and SA scores. This effect was seen in boys and girls, and was most pronounced when the visualizations had a kinesthetic component, that is students were handling 3D physical models of chemical entities.

Coleman and Gotch (1998) studied the effect of spatial ability on undergraduates in introductory chemistry courses. They began with the assumption that spatial ability was strongly correlated with achievement in science (a result which has been repeatedly demonstrated for 50 years in cognitive science according to a meta-analysis by Wai et al. 2009). The assumption that SA and science performance are correlated was shown in the Coleman and Gotch research, but the training effect of SA was also demonstrated, indicating that the causal relationship between SA and science performance is in question. Will increasing a student's SA make them better at scientific reasoning, or is the correlation of these two factors based on some other variable? This study also included a longitudinal component which looked at approximately twenty years of student SA scores. They found that SA differences in men and women were decreasing, but it was entirely due to men's scores falling, as opposed to women's scores rising.

Yang et al. 2003 showed that teaching college undergraduates improved their SA and general chemistry knowledge through the use of animations, as opposed to static diagrams. The animations used included narration, and instructor lectures to provide additional context to the animated images. The necessity of narration and lecture in the use of animations was also demonstrated with undergraduates by Tasker (2016) and in secondary students by Kelly (2016).

Other authors discussing animations in chemistry have found web-based animations to be an effective supplement to undergraduate learning (Morozov et al. 2004, Lester et al. 1999, Frailich et al. 2009, Calik et al. 2010). All of the preceding studies provided students with animated chemical reactions or processes and found improved student grades with those using the animations as a study tool (as compared to a non-animation using control group). None of the above papers explicitly discuss the spatial abilities of the students in the study population, but the use of visuals to effectively teach scientific concepts is well documented (see Harle and Towns 2011 for a review of spatial ability literature in chemistry).

Spatial ability in engineering

Engineering, as a field, is highly dependent on spatial ability Consequently, several studies about how to teach these skills have been published. The SA literature in engineering reaches the same conclusions as seen in the sections on chemistry and geology, above. That is, training students in spatial ability may improve their SA scores (Alias et al. 2002, Martin-Gutierrez et al. 2010, Potter et al. 2009), but improved SA does not always lead to greater content acquisition (Prieto and Velasco 2010). Each of the above studies used different methods for teaching SA to college undergraduates, for example 2D paper-based drawings (Alias et al. 2002), technical drawing (Martin-Gutierrez et al. 2010), and augmented reality (Potter et al. 2009). While all of these approaches showed improvements in student SA scores, the methods used were greatly different, from low tech (pencil and paper drawing) to high tech (augmented reality, using a mobile device to provide additional information about a real-world object). This again indicates that the method of teaching SA is less important than explicitly teaching these skills to novice learners (as seen in Piburn 2005).

Spatial ability in physics

In physics, a few studies have examined explicitly the role of SA and physics content acquisition (Kozhevnikov and Thornton 2006, Kozhevnikov et al. 2007, Pallrand and Seeber 1984). These studies have shown that adding visual skills instructions to a physics lab improved both undergraduate SA skills and content acquisition. The most interesting finding in Kozhevnikov and Thorton (2006) is that the undergraduates who began the introductory physics lab with the lowest background SA skills showed the most benefit from working with the computer models. This is in contrast to some other work (e.g., Cohen and Hegarty 2007) in SA that shows the greatest benefit in students who already have good visual skills. (VS is defined in this dissertation as the combination of visual literacy and spatial ability. This is a new term, unique to this dissertation, but the Cohen and Hegarty paper defines a suite of spatial ability and visual literacy skills closely in line with my use us the term 'visual skills'). Cohen and Hegarty (2007) found that use of external representations as an aid for completing visualization tasks was much greater in students with higher SA, and strongly correlated with performance on other types of SA-based tasks.

Non-discipline specific spatial ability

Some general research on SA that does not fall into any specific discipline is outlined below. These papers provide background on how students acquire SA skills, which students benefit most from different types of SA teaching, and how SA is used by students.

Kastens (2010) outlined a brain science perspective on SA by detailing some of the key differences between SA and VL, by defining two separate visual systems in the brain. These systems are broadly called "what" and "where." The "what" system is closely related to VL in that this is the part of the brain that makes sense of the content of an image. The "where" system is closely related to SA in that this system is the part of the brain that builds a model of a structure, and keeps the various parts in order. The cognitive science behind how the brain constructs and image is only tangentially related to the instruction of SA and VL discussed in this dissertation (and this topic is still an active area of research), but a brief overview of the cognitive science behind mental image construction follows. Wai et al. 2009, Harle and Towns 2011 both examine the history of spatial ability as a cognitive discipline, and explain that spatial ability has repeatedly been demonstrated as a strong correlate with success in STEM (science, technology, engineering, and math) fields. Both papers go on to recommend the nurturing of students with high spatial abilities in STEM fields, but do not provide any definite guidelines for how to do so.

Pickering (2014) examined the cognitive load and working memory theories behind the acquisition of visual literacy in anatomy students. People have a finite amount of working memory that cannot be modified by instruction or training, so visual aids to learning must help the working memory by reducing the cognitive load. Information in working can be consolidated into long-term memory (learning), but only if extrinsic factors (such as visuals) do not interfere.

Foo et al. (2013) describe the mental workload principles behind using two- and three dimensional images to teach anatomy students. Traditionally students in anatomy are given two-dimensional images to emphasize spatial relationships, while three-dimensional images help with understanding the shape of an object. Foo et al. (2013) described a method of using ony 3D images to reduce cognitive load by reducing the number of extraneous images students view. It was found that mental workload was decreased, and accuracy of identification increased in first-year anatomy students when they viewed only 3D images.

Despite all of the benefit shown to learning visual skills, students still seem unlikely to know how best to apply these skills in new situations (Stieff et al. 2010). Steiff and colleagues indicate that acquisition of visual skills is unrelated to a student using those skills on an exam. Steiff and colleagues interviewed undergraduate students enrolled in an organic chemistry course using a thinking aloud protocol to solve chemistry problems similar to those they would find on an exam. The author found that students rarely used the visual thinking skills they had learned in the course, and fell back on algorithmic thinking. This is in contrast to experts in chemistry, who used image-based reasoning for the majority of their thinking.

Some authors (e.g., Darian 2001, Anderson and Dietrich 2012, Serpente 2016) have examined the role of visuals in textbooks. Ideally these visuals would lead students to greater visual thinking, and help them to acquire VL and SA skills, but this is rarely the goal of the textbook authors and illustrators. The main problem identified in the above papers is the different ways in which experts and novices interpret images. Experts and novices will use images differently, and consequently are able to generate different information from the same image. The research cited above offers no definitive solution to this problem, but rather seeks to outline all of the possible approaches to the problem. They advise care in the selection of images, and specify several criteria that must be addressed when choosing images for a science textbook.

Good spatial ability skills seems a given for computer graphics students, but this assumption has been challenged (Mohler 2006). Mohler argued that computer graphics instructors cannot assume their students have an equal SA background, and specific classroom tasks should be used to improve SA. Several activities (e.g., computer-based drawing, use of physical models) are suggested, with hand sketching on paper showing good results, with the added bonus of that it is inexpensive and easy to deploy. Other authors (Czarnolewski and Eliot, 2012) have also found that sketching by hand improves spatial ability and memory.

Spatial ability in anatomy

Spatial ability has been studied extensively in anatomy with many experiments using similar designs to those in other fields. The consensus view of the collected literature in anatomy is that SA is a crucial ability for students and future practitioners (Langlois et al. 2014, Keehner et al. 2006, Pahuta et al. 2012, Provo et al. 2002, Lufler 2012, Lufler et al. 2012, Luursema et al. 2008, Boudreau et al. 2008, Hegarty et al. 2009, Wanzel et al. 2002, Fuks et al. 2009, Garg et al. 2001, Nicholson et al. 2016, Canty et al. 2015, Beck et al. 1978, Hoyek et al. 2014, Nugent et al 2012a, Nugent et al. 2012b, Sweeney et al. 2014), but there is a still an active debate about the best ways to teach SA while delivering content (Allen et al. 2014, Azer and Azer 2016, Bareither et al. 2013, Faurie and Khadra 2012, Garg et al. 2001, Gradl-diestch et al. 2016, Keehner 2011, Keehner et al. 2008, Khot et al. 2013, Kotze and Mole 2015, Knobe et al. 2013, Kooloos et al. 2014, Moscova et al. 2014, Murphy et al. 2014, Ngan et al. 2010, Ngan et al. 2012, Nguyen et al. 2014, Nguyen et al. 2011, Nguyen et al. 2009, Noel 2013, Preece et al. 2013, Richardson-Hatcher et al. 2014, Ruisoto et al. 2012, Ruiz et al. 2006, Ruiz et al., 2009, Saltarelli et al. 2014, Schwibbe et al. 2016, Smith 2015, Smith et al. 2015, Sweetman et al. 2013, Tam 2010, Topping 2014, Trelease and Nieder 2013, Vorstenbosch et al. 2013, Weber et al. 2016, Willis and Martin 2016, Yammine and Violato 2014,). Many of these studies repeat the same experimental designs or results with only minor changes, so several salient examples are examined in detail in the following paragraphs.

The need for strong SA skills in anatomy students is well demonstrated, with each of the following sources showing a correlation between SA in anatomy students and various measures of success. Keehner et al. (2006) showed a strong correlation between SA skills and laparoscopy skills in surgeons. The authors even show that SA was a stronger correlate with surgical skill than general aptitude (also shown by

Schlickum et al. 2016 and Maan et al. 2012 for a meta-analysis of predicitive factors in surgical training). An earlier study (Wanzel et al. 2002) demonstrates the same results in a population of general surgeons, and also shows that surgeons with lower SA can be helped by practice and feedback. In a similar vein Boudreau et al. (2008) discuss the importance of clinical observation skills for clinicians of all specialties. The authors go on to define the guiding principles of clinical observation, and emphasize the importance of introducing these to medical students as soon as possible. They have also developed a series of modules designed to teach observation through practice, but no results on efficacy have yet been published.

Hegarty et al. (2009) also showed the need for SA skills, in this case for practicing dentists. They found a correlation between dental reconstruction performance and SA, but did not see a correlation with general anatomy performance and SA. This may be due to the fact that SA is more strongly assessed in incoming dental students than it is for medical students, or other anatomy students.

Lufler et al. (2012) demonstrated a strong predictive effect of medical student SA on gross anatomy performance. This paper also suggests that intervention may be necessary to improve SA skills in students with lower SA scores, but does not offer any suggestions. This paper also re-confirms a small amount of passive acquisition of SA for all anatomy students, similar to the effect seen in geology (Titus and Horsman 2009).

The following sources all look for methods of improving SA in anatomy. Many have been tried, and every teaching intervention that has been published shows some effect on SA, but there is no consensus on the best practice for teaching SA in anatomy. Methods tested include passive learning (Vorstenbosch et al. 2013), 3D computer based models (Ruisoto et al. 2012, Ruiz et al. 2009, Garg et al. 2001, Pickering 2014, Roach et al. 2016), Animations (Ruiz et al. 2009, Evans 2011), Drawing (Ruiz et al. 2009), 3D images (Luursema et al. 2008), anatomical cross sections (Provo et al. 2002), and surgery simulations (Keehner et al. 2006, Roach et al. 2012).

Vorstenbosch et al (2013) showed that medical students passively acquire greater spatial ability simply through studying anatomy, in the absence of any specific spatial ability interventions. Passive acquisition of SA through the learning of course content has been shown in other fields (Titus and Horsman 2009) and this effect has also been seen in anatomy (Vorstenbosch et al. 2013). Vorstenbosch et al. (2013) also demonstrated a reciprocal effect between SA and anatomy, that is learning one leads to better learning of the other, but they do not offer any specific interventions to aid this process.

The use of 3D computer models to teach and learn anatomy has been a big topic for many years, but results are mixed. Garg et al. (1999a, 1999b) showed that computer models were no worse than traditional images for student learning. More recently, more favorable results have been obtained, perhaps due to the improvement in computer-produced visuals in recent years. Ruiz et al. (2009) found that three-dimensionality was the most important factor dictating the usefulness of an image. Ruisoto et al. (2012) showed an increase in clinical reasoning for neuroanatomy students who used 3D computer images to study, over those who used only flat images. Animation of images only occasionally correlates with learning of content (Ruiz et al. 2009). This review article found a mixed bag of results when examining the effectiveness of animated images for student learning in anatomy. Keehner et al. (2008) demonstrated an advantage to animated images over static images, but only in learning SA, not course content.

Multiple views of any type have been shown to help student learning; this is the idea behind animation and 3D models as a teaching tool, because each of these methods can potentially offer multiple views of the same object (Ruiz et al. 2009). Another way of increasing the number of images and number of different types of images a student uses is the use of cross sectional views. Provo et al. (2002) used cross sectional views of a dog's head to help veterinary anatomy students learn head anatomy. They found that the group using the cross sections had significantly higher exam grades than the group who used dissection alone (Provo et al. 2002).

Stereopsis is another intervention that has been tried in anatomy as well as other fields, with mixed results. Stereoscopic images are a type of 3D image that relies on projecting two slightly different angles of the same image to each eye, much the way modern 3D movies, or the old-fashioned stereopticon, create the illusion of 3D (also called binocular parallax). In chemistry, stereoscopic views (produced with a virtual reality headset viewer) did not help students any more than traditional 3D renderings on a flat screen (Trindade et al. 2002). In a more recent anatomy study, stereoscopic images were shown to benefit students with lower base SA scores, but time spent with images was a bigger predictor of usefulness than the specific rendering of the image (Luursema et al. 2008). In another study, neuroscience undergrads using stereoscopic 3Dimages to learn brain anatomy showed improved knowledge retention over traditionally taught students, but no measures of SA were made (de Faria et al. 2106).

Summary of Visual Literacy and Spatial Ability

Spatial ability, as described above, has been well studied for decades. There is broad agreement that spatial ability correlates with student performance in STEM fields, but the causal relationship between these two factors has not been elucidated. Additionally, improving SA skills in students through training is now widely accepted, but improvements in science knowledge related to SA gains are not always supported in the literature. It seems that improving SA in students with low SA is possible through a wide variety of methods, but none of these methods have led to consistent improvements in knowledge gains, or success in science fields. Results in SA studies in anatomy parallel those seen in other sciences. One goal of this dissertation research is to continue looking at improving SA in anatomy students, and how gaining SA skills relates to learning anatomy content. The projects designed around this question can be found in Chapters 5-8.

Visual Literacy was previously defined in chapter 1. Remember, visual literacy is related to spatial ability, but it is presently considered a completely separate cognitive skill. Visual literacy research, especially in anatomy, is greatly lacking. In a search of the journal Anatomical Sciences Educator (a journal which publishes research based on teaching anatomy) only 13 results dealing with VL were found (search conducted on June 1, 2016). Of these 13 results, only four articles actually dealt with the teaching and assessment of visual literacy (Backhouse et al. 2016, Bardes et al. 2001, Bell et al. 2014, Pickering 2014). The other major goal of this current dissertation project is to examine visual literacy in anatomy students. The specific research questions dealing with VL in anatomy are detailed in the next chapter. Results and detailed methodologies concerning the VL research projects are in chapters 4-6.

CHAPTER 3: Materials, Methods, and Research Questions

This chapter outlines the specific research questions which guided the research detailed in the chapters 4-8, followed by a description of the instruments and methods used in each facet of the research. Before explaining the research questions and methods, it is worth noting the populations and courses examined in the research. Samples from each course syllabus can be found in Appendix C.

As a reminder of the current state of visual literacy and spatial ability research, see Chapter 2, but a brief summary follows.

Spatial ability, as described in Chapter 2, has been well studied for decades (Wai et al. 2009 for a meta-analysis of 50 years of spatial ability research). There is broad agreement that spatial ability correlates with student performance in STEM fields, but the causal relationship between these two factors has not been elucidated. Additionally, improving SA skills in students through training is now widely accepted, but improvements in science knowledge related to SA gains are not always supported in the literature. It seems that improving SA in students with low SA is possible through a wide variety of methods, but none of these methods have led to consistent improvements in knowledge gains, or success in science fields. Results in SA studies in anatomy parallel those seen in other sciences. One goal of this dissertation research is to continue looking at improving SA in anatomy students, and how gaining SA skills relates to learning anatomy content. The projects designed around this question can be found in Chapters 5-8.

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Student populations and courses examined

This section will provide background information detailing the students and courses examined in the following research. All research (unless otherwise noted) was conducted using students at the Bloomington, Indiana campus of Indiana University. Six different undergraduate and medical courses were analyzed in this research:

- **ANAT-A215 Basic Human Anatomy** (referred to as A215 throughout this dissertation) is a one-semester, introductory course for undergraduates consisting of three hours of lecture and four hours of laboratory time each week. Lab time is used for students to study anatomical models, histological images, and prosected cadavers. Four multiple-choice lecture exams are given during the semester. Students also take four free-response lab practical exams that are entirely based on identification. Lecture and lab exams cover the same topics.

The course is taught using an organ system (versus regional) approach, and all body systems are covered in the semester. The course enrolls approximately 400 students in one or two lecture sections, and has twelve lab sections each with 36-40 students. Students are mostly freshmen or sophomores, and come from a variety of academic programs, mostly pre-nursing. This course is offered every fall, spring and summer semester. Further demographic details of the student population may be found in the results section of the following chapters.

- **ANAT-A550/551 Medical Gross Anatomy** (referred to as A550 throughout this dissertation) is a two-semester (full-year) anatomy course for first-year medical students (MS1) consisting of two hours of lecture and four hours of laboratory time each week. Students in lab work in teams of four to complete a full dissection of a cadaver. Because a full-body dissection is completed in this course, course topics are organized around a regional approach to anatomy, with specific clinical correlations included in all sections. Student assessment in this course is varied and includes six written exams with multiple-choice, identification, short-answer and multiple-mark questions to assess topics learned in lecture. Students also take six lab practical exams which are mostly identification, but approximately 10% of lab exam questions include higher-order questions about functions and relationships of structures. Students also receive grades for completing problem-based learning exercises during the course. This course enrolls 36-40 MS1 students who all take lectures and labs at the same time. (Two to six graduate students not in the medical school are also typically enrolled in this course, but they have not been included in the results due to their small number, and their differences from the rest of the population). Further demographic details of the student population can be found in the results section of the following chapters.

- **PHSL-P215 Basic Human Physiology** (referred to as P215 throughout this dissertation) is a one-semester introductory course for undergraduates. Each week, P215 students attend lecture for five hours and laboratory for two hours. Topics covered include the physiological basis of all organ systems in the human body, with specific focus on topics of homeostasis, membrane potential, and metabolism. Students are assessed with four multiple choice exams covering lab and lecture material. Additional points are allotted for weekly quizzes and lab write-ups. This course is offered every fall, spring and summer semester.
- **PHSL-P531/532 Medical Physiology** (referred to as P531 throughout this dissertation) is a two-semester (year-long) course for first-year medical students (MS1s). Lectures include the physiological basis of all organ systems in the human body, with specific focus on topics of homeostasis, membrane potential, and metabolism. Students are assessed with four multiple choice exams covering lab and lecture material. Additional points are allotted for weekly quizzes and lab write-ups.
- **Other courses**- Chapter 8 deals with a nation-wide survey of students enrolled in a variety of neuroscience and neuroanatomy courses. Detailed syllabuses of these courses are not available, but the student populations and course descriptions will be discussed in chapter 9.

Research Questions and Methodology of Each Project

Larger Research Questions

The research presented in this document is comprised of a series of smaller projects (also called ‘facets’) all designed to explore a number of larger research questions. This chapter will detail each of those research questions and the assumptions implied in each. This chapter will also provide a brief introduction to each individual project (or facet), and serve as an outline for the remainder of the document.

Research Question 1: What methods do students use to study for anatomy?

The students in this question are considered broadly and come from populations in A215 (anatomy undergraduates), A550(first-year medical anatomy), P215(physiology undergraduates) and P531(first-year medical physiology) as described in chapter 3. Instructors in all listed courses provide students with numerous tips and tools for efficient study, but it is unclear which of those techniques the students use. Study tips provided in all classes include active learning techniques and student-produced drawings (as seen in the syllabus excerpts, Appendix C). Educational research literature indicates that use of the above study techniques is effective, but it is unclear whether there is a correlation between use of the suggested study techniques and final grades in the courses studied (Barger 2012, Husmann et al. 2016, Vasan et al. 2009, Zumwalt et al. 2010). This first question was designed to look at the study techniques students report actually using, and how student use of study techniques compares to the recommendations provided by instructors.

Research Question 2: **How frequently do students use each study technique for the learning of anatomy?**

More specifically, this research question may be subdivided into the following questions:

a. **Do medical students and undergraduates employ different study strategies?**
b. **Do medical students and undergraduates spend different amounts of time with each specific study habit?**
c. **Do students use different study habits in anatomy courses as compared to physiology courses?**

This second research question is closely related to the first, and serves to elucidate some of the other ideas contained in the question of "what methods do students use to study anatomy?" This second question was designed to look more closely at differences in student populations, and if successful study strategies are transferable to new contexts. The students considered are detailed above in the populations section.

Research Question 3: Do different study habits lead to different course outcomes, when controlled for student demographics?

Knowing what activities students are doing in their study time is only the first step in helping them to use that time more effectively. The next obvious step is to discover which strategies, if any, correlate with course outcomes. Again, the educational research literature (e.g., Barger 2012, Husmann et al. 2016, Mitchell et al. 2004, Vasan et al. 2009, Zumwalt et al. 2011) is full of details concerning effective study strategies, but it was unclear how these broad principles apply to the populations considered here. The survey used in this research contained some questions about visual approaches to learning anatomy, and correlations between these visual study methods and final course grades were examined.

Research Question 4: How often do anatomy students use visual study skills?

This question is the central idea guiding the overall research plan. The following questions are all further elaborations of the visual study skills question. The literature review and introduction chapters (see above) are full of justifications and research explaining the utility of visual learning (especially mental rotation and spatial ability) in a variety of fields, including other sciences, and anatomy, but the use of visual study skills in novice students has not been fully explored in the existing literature (to clarify, mental rotation and spatial ability are well explored in the existing literature, but the use of visual study skills, as defined in this dissertation (Chapter 1, Definitions section) is not widely reported).

Research Question 5: Are there differences in student self-reported visual learning measures?

More specifically:

a. **Do students who self-report a preference for visual learning use visual study skills more often in their anatomy courses?**
b. **Do students who self-report a preference for visual learning do better in anatomy course performance metrics?**

This question was designed to look at differences in student perceptions and uses of visual learning in anatomy. Students enter anatomy courses with a wide variety of previous experiences, and it is unclear how those experiences shape a student's study habits. This question asks whether different students use different study habits without any intervention from the instructors or researchers.

Research Question 6: Do student study habits for anatomy change during the semester?

All of the previous questions rely on sampling students at a single time point in the semester. This question allows for the exploration of study habit changes in students during a course, including those habits related to visual learning and spatial ability. It has been suggested in some visual literacy literature (Orion et al. 1997, Titus and Horsman 2009) that simply taking a science course can lead students to changes their habits and increase their visual literacy abilities. As students navigate the challenges of a course, and experiment with new ways of learning, they may change their study habits, without any specific suggestions from instructors.

Research Question 7: Do undergraduates enter an introductory anatomy course with adequate mental rotation skills (MRT scores)? More specifically:

a. **Do mental rotation (MRT) scores change during the semester?**
b. **Do mental rotation scores change, given specific instruction in anatomical drawing?**
c. **Do mental rotation scores correlate with anatomy course performance metrics?**

Previously published literature suggests mental rotation abilities (summarized in the spatial ability section of Chapter 2) of novice students can be highly variable (Faurie and Khadra 2012, Garg et al. 2001, Keehner 2011, Keehner et al. 2008, Ruisoto et al. 2012, Ruiz et al., 2009, Vorstenbosch et al. 2013). In general, students rarely have enough experience with mental rotation (or similar spatial ability tasks) to have good MRT scores, which can make learning anatomical relationships more challenging (Boudreau et al. 2008, Codd and Choudhury 2011, Fuks et al. 2009, Garg et al. 2001, Hegarty et al. 2009,Keehner et al. 2006, Lufler et al. 2012, Luursema et al. 2008, Provo et al. 2002, Wanzel et al. 2002).

Research Question 8: Does the use of an online software tool for anatomy drawing change student mental rotation scores, or their attitudes and use of visual learning study skills?

The previous question (#7) investigates the use of in-class drawing as a pedagogical intervention to teach visual literacy and mental rotation skills to students. This question (#8) investigates whether drawing lessons can be effective if delivered through web-based video tutorials.

Research Question 9: What are the best ways to study anatomy, and is visual learning an important part of the student experience? What are the pedagogical implications of the above questions? That is, what should instructors do to ensure students are getting the most benefit from an anatomy course?

This question is not a specific measurable question to be answered by the research in this dissertation, but more a guiding principle and a reminder of the overarching goals of all the above research questions put together. All of the preceding questions were treated as largely separate to make each individual project as specific as possible, but all of the questions work together to address to problem of student learning in anatomy, which is the ultimate goal of the entire series of research projects. Question 9 is almost impossible to answer in isolation, but it is the ultimate goal of this dissertation to address this problem, and provide answers to the question of "best way to study." While evaluating or measuring 'best way to study' may not be possible, the answers to the preceding questions will inform the broad, theoretical question posed in Question 9. Additionally, the teaching methods employed by instructors will influence how students study, so identifying successful study strategies has obvious pedagogical implications; teaching methods used in the classroom, and advice given to struggling students will be influenced by the answers to these research questions.

Methodology

To answer the above questions, a series of individual facets (or projects) relating to the overarching research goals were designed to examine the ways in which students study anatomy. The next section will discuss the instruments used to conduct the research including surveys and mental rotation tests. After that, a brief overview of each individual facet will be included, with detailed methodology and results to be found in the following chapters.

Facet	Populations Examined (Chapter 3)	Main Research Question (Chapter 3)	Subordinate Research questions	Chapter
1. Study Skills Survey	A215 P215 A550 P531	What study methods do students use?		4
2. Visual study skills	A215	Do students use visual study methods?	Does the use of visual studying change during the course?	5
3. Mental Rotation	A215	How much spatial ability do students have?	Does spatial ability change during the course?	6
4. In-Class Drawing	A215	Does the use of in-class drawing lessons improve SA or VL?		7
5. Web-based video tutorials	Various	Does the use of web-based drawing tutorials improve SA or VL?		8

Table 3.1- The relationship between research questions and the individual facets of the larger research plan.

Instrumentation used across multiple facets of the dissertation

Each of the following facets described, relied on surveys to gather data about student perceptions and habits. The survey was originally designed using principles found in Fowler (1985) and was based on the question format used by Biggs et al. (2001). (For additional details on the survey design, evolution, and validation see the survey appendix A). The survey also was used in the recently published Husmann et al. (2016), which contains further details about the evolution and validity of the survey. The original survey was designed to look only at student study habits and collect background demographic data (Project 1 “What study methods do students use?” 2010-2011). The survey consisted of 26 questions, including questions about study methods used to prepare for exams, and basic demographic information. Each survey question asked the student to rate how frequently they used each study method listed on a five-point, Likert-type scale. (For example, a question may ask “I read the class notes to study” and the response choices are A. always B. frequently C. about half of the time D. rarely E. never). Further revisions of the survey added more specific questions about visual study skills, and perceptions of visual learning (Project 2 “Visual Literacy” and Project 3 “Mental Rotation”, 2011-2014. As an additional note, even though project 3 is entitled “Mental Rotation”, it also assessed visual literacy using the same survey as the previously mentioned projects).

Another piece of the research introduced a mental rotation test (MRT) to assess students’ spatial ability skills (Bodner and Guay 1997). Finally, pedagogical interventions were employed in an effort to teach visual learning skills, and improve mental rotation abilities (Project 4 “Drawing and visual literacy” and Project 5 “web-based drawing”, 2013-2014). All data were collected from students at Indiana University Bloomington, including students in the Indiana University Medical School (see above; section “Student Populations” unless otherwise noted (viz. Project 5 “on-line drawing tutorials”). IRB approval was obtained for each project; approval numbers are listed in the relevant methodology sections, as well as in Appendix D. The web-based software tool used was *Draw It to Know It* (Draw It to Know It 2016). This software was originally designed as a review tool for neurology residents, but was substantially re-written to work with neuroanatomy and neuroscience content at all levels. The aim of the software is to present neuroanatomy concept in a series of short (3-8 minute) video tutorials, in which the student draws anatomical structures along with a narrator demonstrating the drawing. The tutorials also include information about the functional aspects of the anatomy being described.

Project 1, "What methods do students use to study anatomy/physiology" 2010-2011

Project 1 was designed to answer research questions 1-3, namely "how do students study anatomy/physiology, how frequently do students use each study strategy, and does it change course outcomes." This project also aimed to answer each of the subcategories included in the above research questions. In this project, four populations of students were sampled; medical students in anatomy (n=36), medical students in physiology (n=36), undergraduates in anatomy (n=469), and undergraduates in physiology (n=238). Each of the provided n-values represent the total sample population, but the number of students completing all parts of the survey research were often lower, which will be explained in the results. Medical students in the study population were all first-year medical students (MS1), undergraduates included in the sample population included students from all four years of undergraduate coursework.

To examine the question of study skills used in the listed courses, a paper-based survey was given to all enrolled students near the end of their course. For the undergraduate course (A215) this was in the fall of 2010, for the medical course (A550/551) this was spring of 2011. Students were not mandated or incentivized to complete the surveys, but were encouraged to do so, using a recruitment script (APPENDIX D) approved by the IU IRB (IRB#: 1010002079). Students were also provided with an informed consent document (later re-named as a 'Study Information Sheet') to explain potential risks and benefits of participating in the research (APPENDIX D). Students who opted to complete the survey did so during normal class time, and returned the completed surveys to a third-party investigator so neither the researcher or classroom instructor would know who participated. Surveys were then de-identified using a random number which was then tied to that specific student's anonymous course grade, to correlate survey responses with course performance outcomes.

At the completion of the semester, survey data were compiled into a database (Excel, Microsoft 2010) and matched with course grades. These paired data were then analyzed using SPSS 21.0 (IBM 2012). A correlation matrix was created to explore the survey responses which correlated most strongly with final grades. Latent variables were pulled from the data using an exploratory factor analysis as a way of finding which study skills and demographic traits naturally clumped together in the dataset (these techniques were derived from Hinkle et al. 2002 and explained with help from the IU Statistical Consulting Center). These latent variables were then correlated (bivariate Pearson correlations) with final grades to find the most effective study strategies. A preliminary version of this project was presented at the Experimental Biology conference in 2011 (Barger 2011).

	Anatomy	Physiology
Undergraduates	Fall 2010, n=128	Fall 2010, n= 181
Medical Students (MS1)	Spring 2011, n=25	Spring 2011, n=25

Table 3.2- A table illustrating the sample populations and number of participants in project 1 “What study methods do students use?” The specifics of this study are in chapter 4.

Project 2, “Visual Literacy in Anatomy” 2011-2013

Having established a baseline of student study habits in Project 1, Project 2 was designed to look more specifically at the visual approaches students used in their studying (research questions 3-6). The methods used in Project 2 are largely similar to Project 1, with a few exceptions. One minor change was that the surveys used in Project 2 were edited based on student and instructor feedback to include additional study-skills questions, and edited for clarity. Institutional Review Board approval (exempt protocol) was granted (IU IRB#: 1112007654). A more significant change to the surveys used in Project 2 was the inclusion of questions specifically related to use of visual study skills (for examples of changes see Appendix A).

Additionally, this project only sampled undergraduates in anatomy, ignoring medical students (for small sample sizes), and physiology students. Physiology students were excluded from this (and future) projects to focus the results specifically on anatomy. It was also found in the earlier project that physiology students tended to use more verbal (versus visual) approaches to studying, and it was believed that their potential contribution to visual studying research would be minimal.

The newly-designed, visually-focused surveys were then deployed to anatomy undergraduates (n=469, the number enrolled in A215 “Basic Human Anatomy”) at the beginning and end of the semester, using the same IRB protocol from the earlier project. This project continued to survey anatomy undergraduates for three semesters across three years. Demographic data indicated that student populations were statistically the same in each of the courses surveyed (See individual methodology chapters for demographic details and results, chapter 5). The collected data were again entered into a database (Excel, Microsoft 2010)) and analyzed using SPSS 21.0 (IBM 2012). A correlation matrix was created to explore the survey responses which showed the greatest effect. Latent variables were pulled from the data using an exploratory factor analysis as a way of finding which study skills and demographic traits naturally clumped together in the dataset. These latent variables were then correlated (bivariate correlations) with final grades to find the most effective study strategies. This data analysis also used the added technique of comparing visual studying strategies with other active learning approaches, as well as correlating visual study strategies with final grades. Because this survey also included questions about a student's own perception of visual learning, the data analysis allowed for comparisons of high-visual and low-visual students as an independent variable compared with the other variables defined in the dataset.

Because student survey data were collected at two different time points in the semester, this dataset was also used to analyze research question 6, "do study habits change during the semester?" For this analysis, paired students responses (from the early- and late-semester surveys) were compared using t-tests to see if the student population (as a whole) showed any significant changes in study habits as a result of their enrollment in an anatomy course. Preliminary results from this study were presented at the Experimental Biology conference 2012 (Barger 2012).

Having examined student study habits and visual literacy measures, the next project considers spatial ability, and its relationship to study habits and visual literacy in anatomy undergraduates.

Project 3 "Mental rotation ability in anatomy students" 2012-2013

This project was designed to research questions 7a and 7c, namely "do students have adequate mental rotation skills in anatomy, and do those skills translate to course performance?" Project 3 used the same survey and IRB protocol as Project 2, with no additional changes to the survey. An additional test of mental rotation ability was also given to students in conjunction with the basic survey. The mental rotation test (MRT) was originally designed by Bodner and Guay (1997) for use with chemistry students, but use of mental rotation tests is well-established as a proxy for spatial ability in the educational literature (Chatterjee and Walker 2011, Faurie and Khadra 2012). The MRT (see appendix B for a full version of the test) contains 20 questions which ask the participant to mentally manipulate a 2-dimensional drawing of a 3-dimensional, geometric object. Each question consists of an example rotation of one object which the participant must then reproduce in a new object, via analogy, and choose the correct answer from a multiple-choice list of four options. The final score on the test is calculated out of twenty points, based on the number of correct answers.

The responses from the whole class were then averaged, and individual students were divided into a high-MRT and low-MRT score group, separated by the median score. The high- and low-MRT variable was then introduced into a correlation matrix with the other survey variables (as above) to examine which factors most strongly correlated with MRT scores. MRT scores were also correlated with final grade to answer research question 7c.

Because MRT scores were collected at two time points in the semester, changes in whole-class performance were analyzed using a t-test to look for statistically significant changes in MRT scores during the semester of anatomy.

Preliminary results from this study were presented at the Experimental Biology conference 2013 (Barger and Husmann 2013).

The three projects outlined above all look at what students do without any intervention from instructors, and how study habits, visual literacy, and spatial ability all change during an anatomy course. The following projects each implement pedagogical interventions designed to explicitly teach visual literacy and mental rotation.

Project 4 "Anatomical drawing and study habits" 2013

The first three projects explained above only collected data from students without suggesting or implementing any changes in course design or study habits. Project 4 was created around a pedagogical intervention designed to actively teach students how to employ more visual skills in their studying. Project 4 looked at research questions 1-8, re-assessing the baseline study habits of anatomy undergraduates, testing their mental rotation ability, and teaching them ways to improve MRT scores and course grades. Institutional Review Board approval (exempt protocol) was granted (IU IRB#: 1301010307).

Project 4 used a quasi-experimental design in the anatomy undergraduate classroom. In spring of 2013, the anatomy course was taught as two separate sections (n=252 and n=263), with identical course goals, labs, and exam formats (See APPENDIX C for course syllabi). Although there were minor differences in syllabus and some specific exam questions, these differences were not considered important enough to confound the results, because previous semester course outcomes and grades were similar between the two sections.

One section of the lecture portion course was taught traditionally with only didactic lectures, while the other lecture section incorporated a series (6 total) of visually-focused lectures in which students drew anatomical objects along with the guest-instructor (me, your humble author, dear reader). The visually-focused lecture covered the normal anatomy content of the course, but used student-produced drawings as a supplement to the provided anatomical images. Six visual lectures were delivered on the topics of bone development and anatomy, skin histology, renal anatomy, cardiovascular anatomy, special senses, and cranial nerves.

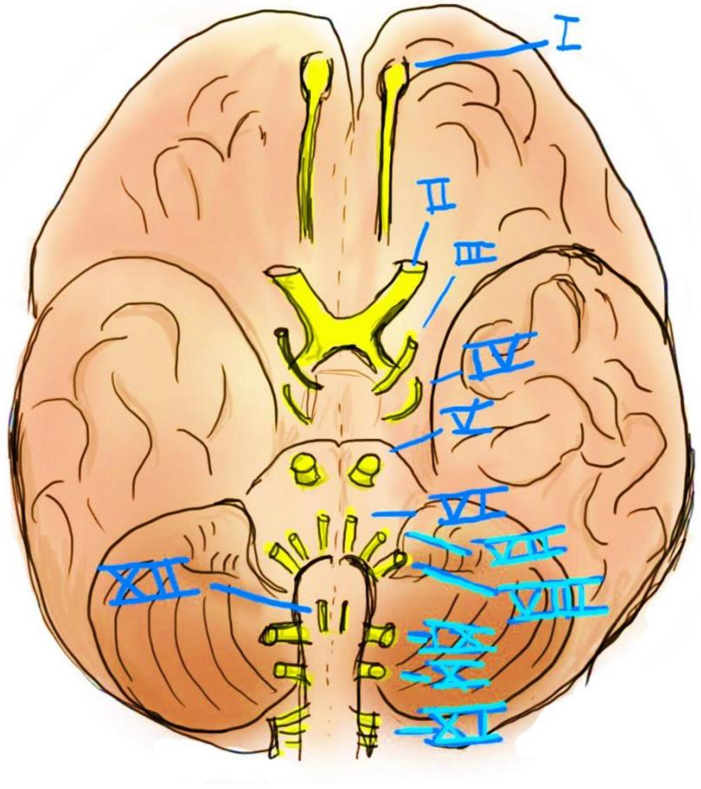


Figure 3.1- an example of the drawings created during the visual lectures. This image was later redrawn in color, but is indicative of the type of illustrations produced. From visual lecture #6- “Cranial Nerves”

Visual lectures also provided students with a basic understanding of how to ‘read’ and create anatomical images, focusing on the choices that are made in creating an image, and images as a medium of communication. For more details on the background of visual literacy principles employed, see chapter 2's discussion on visual literacy.

	Visual('experimental') anatomy lecture class	Traditional ('control') anatomy lecture class
Early-semester survey/MRT	n=160	n=105
Late-semester survey/MRT	n=63	n=90

Table 3.3- The above table illustrates the number of participants in each of the surveys used.

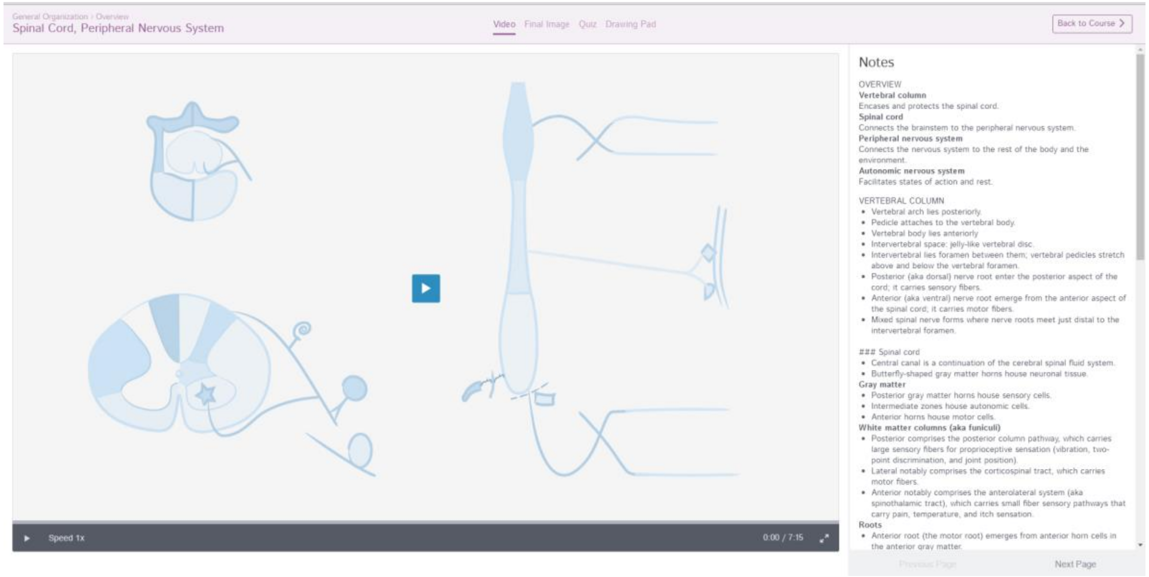
Students in both populations (visual lecture and traditional lecture) were given a survey (the same survey used as in Project 3) and a mental rotation test (MRT) at the beginning and end of the spring 2013 semester, following the same IRB protocol as in earlier projects. Data were de-identified, collected in a database (EXCEL Microsoft 2010), and paired with anonymous course grades. Both sections were analyzed using SPSS 21.0 (IBM 2012). A correlation matrix was produced as before to explore the grouping of variables in student performance. Latent variables concerning student active-learning and visual-learning approaches were created. T-tests comparing the traditional lecture and visual lecture sections final scores were run. Preliminary results from this study were presented at the Experimental Biology conference 2014 (Barger 2014).

Preliminary results from the in-class drawing exercises indicated that six drawing lessons were too few to be really effective, so the following project (Project 5 "Web-based drawing instruction") was developed to increase student exposure to the principles of drawing as a way of learning.

Project 5 "Web-based drawing instruction" 2014

Project 5 was designed to answer research question 8, "can a web-based tool be used to teach visual studying or mental rotation?" This project used a slightly different form of the earlier survey (see Appendix A), as it had to be re-written for deployment online, and had a different student population. The mental rotation test (MRT) was the same as in previous projects.

The web-based software tool used was *Draw It to Know It (*DITKI*)*(Draw It to Know It 2016). The DITKI software was originally designed as a neuroanatomy review tool for neurology residents, but was substantially re-written to work with neuroanatomy and neuroscience content at all levels. The aim of the DITKI software is to present neuroanatomy concept in a series of short (3-8 minute) video tutorials, in which the student draws anatomical structures along with a narrator demonstrating the drawing. The tutorials also include information about the functional aspects of the anatomy being described.



Spinal Cord, Peripheral Nervous System

Notes

OVERVIEW
Vertebral column
Encases and protects the spinal cord.
Spinal cord
Connects the brainstem to the peripheral nervous system.
Peripheral nervous system
Connects the nervous system to the rest of the body and the environment.
Autonomic nervous system
Facilitates states of action and rest.

VERTEBRAL COLUMN

- Vertebral arch lies posteriorly.
- Pedicle attaches to the vertebral body.
- Vertebral body lies anteriorly
- Intervertebral space: jelly-like vertebral disc.
- Intervertebral lies foramen between them; vertebral pedicles stretch above and below the vertebral foramen.
- Posterior (aka dorsal) nerve root enter the posterior aspect of the cord; it carries sensory fibers.
- Anterior (aka ventral) nerve root emerge from the anterior aspect of the spinal cord; it carries motor fibers.
- Mixed spinal nerve forms where nerve roots meet just distal to the intervertebral foramen.

Spinal cord

- Central canal is a continuation of the cerebral spinal fluid system.
- Butterfly-shaped gray matter horns house neuronal tissue.

Gray matter

- Posterior gray matter horns house sensory cells.
- Intermediate zones house autonomic cells.
- Anterior horns house motor cells.

White matter columns (aka funiculi)

- Posterior comprises the posterior column pathway, which carries large sensory fibers for proprioceptive sensation (vibration, two-point discrimination, and joint position).
- Lateral notably comprises the corticospinal tract, which carries motor fibers.
- Anterior notably comprises the anterolateral system (aka spinothalamic tract), which carries small fiber sensory pathways that carry pain, temperature, and itch sensation.

Roots

- Anterior root (the motor root) emerges from anterior horn cells in the anterior gray matter.

Figure 3.2- an image from the Draw It to Know It software. The drawing tutorial panel is visible on the left of the image, with the right pane of the image showing the terms and concepts to be learned in this tutorial.

This DITKI software had not previously been evaluated as to its educational effectiveness, so Project 5 was designed to assess the software using the same tests as used in the previous educational research projects described in this document.

The sample population for this project (n=97) came from a total population of undergraduate and professional students (n=1352) in nearly 40 different neuroanatomy and neuroscience courses from across the United States.

These students were enrolled in a variety of courses at all educational levels, including undergraduates, medical students, physical therapy students, and osteopathic medicine students. Surveys and MRTs were deployed through the *DITKI* website, and a Study Information Sheet (previously called Informed Consent Statement) allowed students top opt-in to the data-collection portion of the project (IU IRB#: 1310535940). Those students who opted in completed a survey at the beginning of their neuroanatomy course, and another at the end. They were also asked to complete the MRT at the beginning and end of their neuroanatomy course.

De-identified student data were collected in a database (Excel Microsoft 2010) as before, and analyzed using SPSS 21.0 (IBM 2012). A notable difference in this data analysis is the lack of student final grades. Due the constraints of ethical research across multiple campuses, no course performance metrics were collected, and the data analysis relied on student self-reported satisfaction with the software, and their perceived quality of learning from it. Preliminary results from this study were presented at the Experimental Biology conference 2015 (Barger and Fisch 2015).

Each subsequent chapter will discuss the research projects in greater detail, including results and a discussion of the pedagogical implications of each question about how students study.

CHAPTER 4: Assessing Student Study Habits in Anatomy and Physiology

Many factors have been proposed as predictors of success in college students. Motivation (Phinney et al. 2005), peer support (Harackiewicz et al. 2002), financial support (Karpicke et al. 2009, Phinney et al. 2005), and academic strategies (or study skills) (Aleven et al. 2000, Hmelo-Silver 2004, Robbins et al. 2004), have all been used as predictors of performance in post-secondary education. Broadly considered, these variables can be divided into cognitive (study skills) and non-cognitive (social, financial, and motivational) determinants of success (Robbins et al. 2004). Each of these predictive variables has been shown to have some predictive power of college success when measured across large populations of students, but course-specific predictors are rarely found. A meta-analysis of these various factors indicated that motivation (non-cognitive) tends to predict student retention, while study skills (cognitive) are one of the strongest predictors of GPA (Robbins et al. 2004). All of the above publications examined large groups of college students, with no discipline specific analyses, or analyses of medical students.

The goal of the research facet presented here, is to further examine the cognitive predictors of success. That is, do study strategies have any correlation with course grade in anatomy (or physiology) undergraduates or medical students? It is reasonable to assume that a discipline specific look at predictors of success will not vary greatly from the institution-wide data present in the research literature, however, knowing what anatomy (or physiology) students do outside of class has pedagogical implications. Understanding what successful students do to study can influence the advice given to struggling students, and help instructors ensure course assessments are authentically promoting learning (Hart 1994, Gurung and McCann 2011, Schwartz and Gurung 2012, Wiggins 1990).

Knowing that cognitive factors play a strong predictive role in GPA, a research project was initiated to measure the study skills of a variety of anatomy and physiology students at Indiana University. In 2010 a project (one facet of the larger dissertation) to survey students about their study habits began. . Populations studied included first-year medical students and undergraduates enrolled in anatomy courses and physiology courses (see table 4.1). The specific focus of this project was to understand how students use their time in preparation for exams, and to find differences between student populations and courses, and to see if any specific study strategies correlated with course success as measured by course percentages (as demonstrated in other course contexts by Gurung and McCann 2011, Schwartz and Gurung 2012) . In the previous chapter, this project was designated as Project 1, and was designed to answer the following research questions as seen in Table 4.1.

Facet	Populations Examined (Chapter 3)	Main Research Question (Chapter 3)	Subordinate Research questions	Chapter
1. Study Skills Survey	A215 P215 A550 P531	What study methods do students use?		4
2. Visual study skills	A215	Do students use visual study methods?	Does the use of visual studying change during the course?	5
3. Mental Rotation	A215	How much spatial ability do students have?	Does spatial ability change during the course?	6
4. In-Class Drawing	A215	Does the use of in-class drawing lessons improve SA or VL?		7
5. Web-based video tutorials	Various	Does the use of web-based drawing tutorials improve SA or VL?		8

Table 4.1**-** The relationship between research questions and the individual facets of the larger research plan.

As seen in chapter 2 (subheading "Visual literacy in anatomy") little has been published about the study skills students bring to their anatomy classes. The work that has been published focuses on specific interventions designed to teach study skills, but the study skills of the novice student in anatomy are poorly understood (e.g., Aleven et al. 2000, Gurung and McCann 2011, Hmelo-Silver 2004, Husmann et al. 2016, Robbins et al. 2004, Schwartz and Gurung 2012). The research presented here examined the study skills that the novice student brings to class. Additionally, students were asked to describe how they spent their study time, in the absence of specific interventions. This study was also a way to find what study habits and methods the most successful students used, by correlating their most-used study habits with their final course percentages (some of these results have been previously reported in Husmann et al. 2016 and Husmann and Barger 2011).

Methodology

Project 1 was designed to answer the above research questions, simply put, "how do students study anatomy/physiology, and do study habits correlate with course outcomes?" This project also aimed to answer each of the subcategories included in the above research questions. In this project, four populations of students at Indiana University were sampled; medical students in anatomy (n=36), medical students in physiology (n=36), undergraduates in anatomy (n=386), and undergraduates in physiology (n=255) (see Table 4.2 for the number of students completing the survey). For additional details of the courses sampled, see Chapter 3, subheading "Student populations and courses examined." Each of the provided n-values represent the total sample population, but the number of students completing all parts of the survey research were often lower, due to absences on survey days, student opt-out, or simple lack of interest. Medical students in the study population were all first-year medical students (MS1), undergraduates in the sample population included students from all four years of undergraduate coursework. These populations were chosen to examine differences in exam preparation between student educational level and course.

	Anatomy	Physiology
Undergraduates	Fall 2010, n=217	Fall 2010 n=181
Medical Students (MS1)	Spring 2011, n=25	Spring 2011, n=25

Table 4.2- The sample populations and number of participants completing all surveys on the methods students use to study anatomy and physiology.

To examine the question of study skills used in the listed courses, a paper-based survey (see Appendix A) was given to all enrolled students near the end of the semester, approximately one week before the final exam. This time for deploying the survey was chosen to collect retrospective data from the students about their entire semester of studying for their course. The survey consisted of 26 questions, including questions about study methods used to prepare for exams, and basic demographic information. Each survey question asked the student to rate how frequently they used each study method listed on a five-point, Likert-type scale. (For example, a question may ask "I read the class notes to study" and the response choices are A. always B. frequently C. about half of the time D. rarely E. never).

Students were not mandated or incentivized to complete the surveys, but were encouraged to do so, using a recruitment script (Appendix D) approved by the IU IRB (IRB#: 110002079). Students were also provided with an informed consent document (later re-named as a 'Study Information Sheet') to explain potential risks and benefits of participating in the research (Appendix D). Students who opted to complete the survey did so during normal class time, and returned the completed surveys to a third-party investigator so neither the researcher or classroom instructor would know who participated. Surveys were then de-identified using a random number which was then tied to that specific student's anonymous course percentage, to correlate survey responses with course performance outcomes. At the completion of the semester, survey data were compiled into a database (Excel, Microsoft 2010) and matched with course grades. These paired data were then analyzed using SPSS 21.0 (IBM 2012). A correlation matrix was created to explore the survey responses which showed the highest correlation with final course percentage. Latent variables were pulled from the data using an exploratory factor analysis as a way of finding which study skills and demographic traits naturally clumped together in the dataset (Tabachnick et al. 2001). These latent variables were then correlated (bivariate correlations) with final grades to find the most effective study strategies.

Results

Initial results showed little differences between discipline (anatomy versus physiology) or student population (undergraduate versus medical), based on single study methods. That is, no single study method correlated strongly with final course grade, in any of the sampled populations (Appendix E, figure E.3 Correlation table is not included here for space considerations, but relevant data are shown in the following figures). As seen in the correlation table provided, the strongest correlation was a *negative* correlation (r=-.205, p=.003) between students who used other websites (non-course specific anatomy resources) and final grade. The lack of any positive correlations between study habits and grade indicates that there may not be a best way to study, but there are some less productive methods students should be aware of.

The next step of the analysis was to look for other trends in the data. An exploratory factor analysis was run on the data (after method explained in Tabachnick et al. 2001), which showed strong grouping of certain sets of study skills. The tables produced can be seen in appendix E, Table E.1. The factor analysis identified two variables (components) which explained the largest portion of the variance in the survey responses. After looking at which of the original survey questions had the highest loading on the new variables, it was clear that active learning and passive learning were the latent variables which explained the most difference in the survey sample. Component 1 in the SPSS output table (appendix E, Table E.2) was termed active learning because it had high loadings with ‘made my own flashcards’, ‘made my own tables’ and ‘made my own drawings’ survey questions. Component 2 was termed passive learning because it had the highest loadings with ‘reviewed lecture notes’, ‘looked at textbook’, ‘looked at a website’ survey questions. A third component (not a strong explanation for survey variance, but with high loading values) was identified as self-efficacy measures. Self-efficacy included questions related to a student’s expected performance on an exam.

Three groups were defined, with these new latent variables being labeled as ‘active learning,’ ‘passive learning,’ and ‘self-efficacy measures.’ Active learning methods included ‘creating my own flashcards,’ ‘making drawings,’ and ‘creating tables of information.’ Passive learning methods included ‘reading the textbook,’ ‘reviewing diagrams,’ and ‘using commercially available flashcards.’ Self-efficacy measures included ‘expected grade’ and ‘I have studied enough.’ Each category was then assigned a score based on how frequently the student reported using each method included in the category. These new categories (latent variables) showed more pronounced differences between populations and courses, as shown in the following graphs.

Figure 4.1 illustrates the correlation between final grade (percentage) and the active learning score the student reported on the survey (for all four groups of students (anatomy undergraduates, physiology undergraduates, anatomy medical students, physiology medical students). It can be seen in the series of scatterplots that all courses had weak positive correlations between active learning and grade. None of the correlations are strong or statistically significant, but the fact that all courses showed the same trends is indicative of a real pattern in the data.

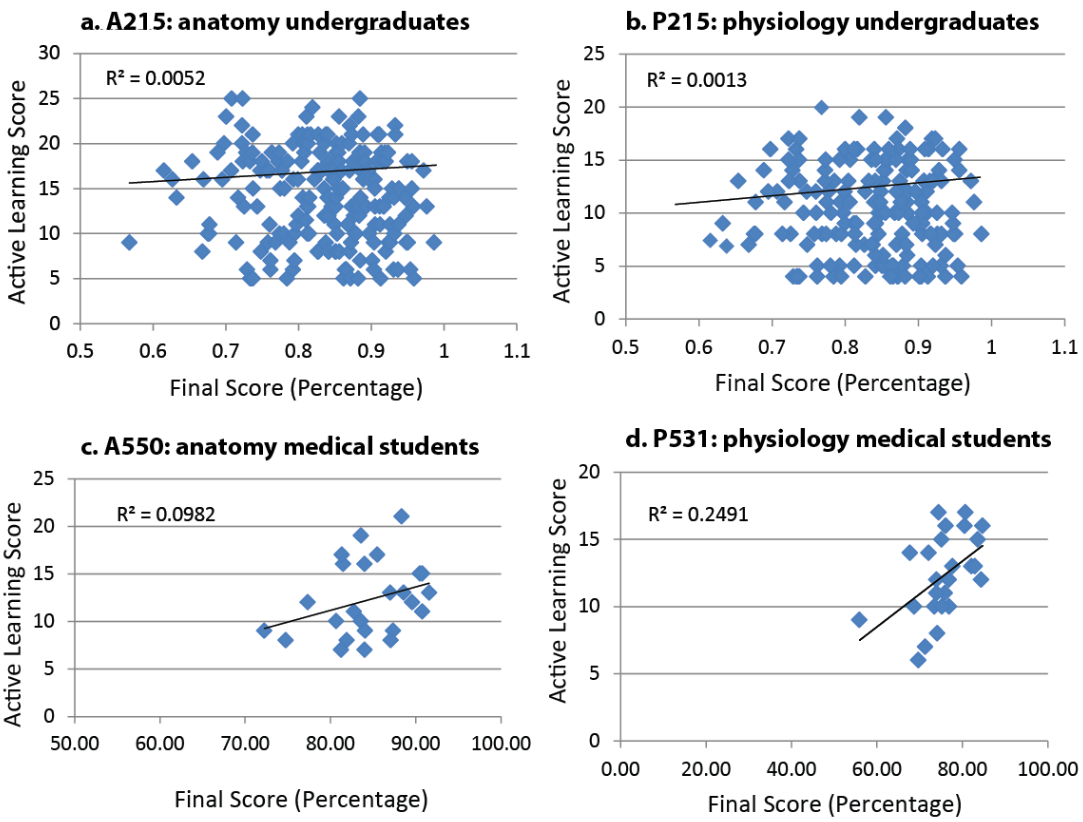


Figure 4.1- Scatterplots representing the correlation of active learning approaches with final grade in the four populations sampled.

Figure 4.2 shows the correlations between passive learning approaches and the student's final grade (percentage). Again, the r^2 values are low, and the p-values are above .05, but the fact that all courses showed the same trend is indicative of a pattern. In this case, frequent use of passive learning approaches is negatively correlated with grade. The correlations between passive learning and grade are all slightly stronger than active learning and grade. While active learning methods may not necessarily be the best way to study for anatomy or physiology, students should be made aware that passive learning approaches are usually worse. Additionally, the correlation between passive learning and grade may point to an underlying non-cognitive factor (e.g., motivation or social factors) influencing student achievement that is causing the study habits (Robbins et al. 2004).

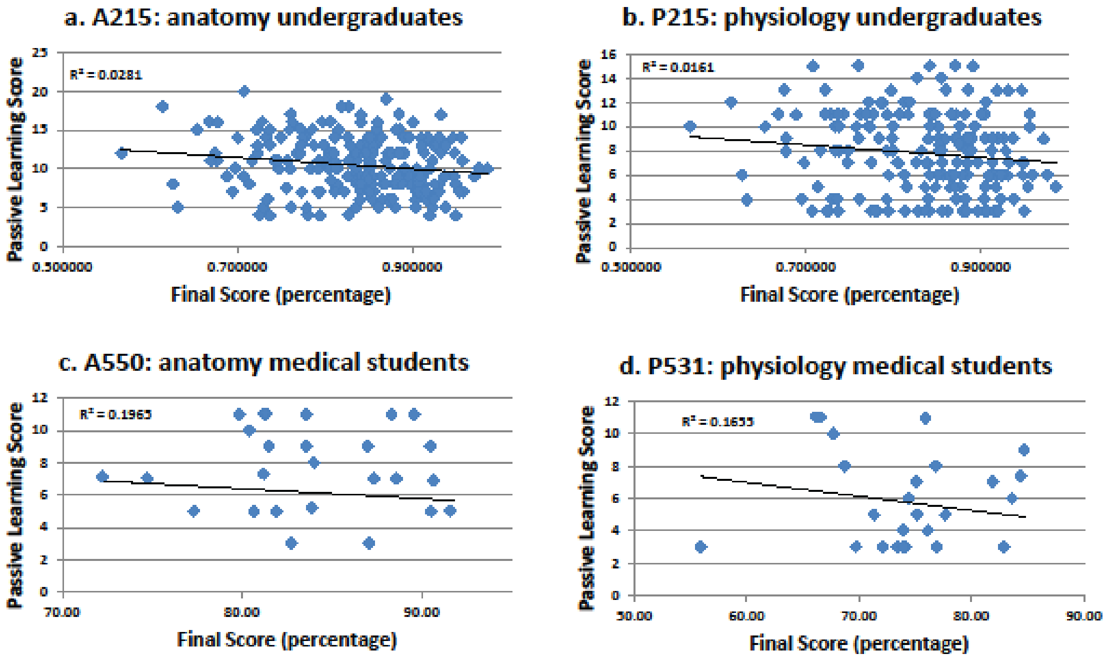


Figure 4.2- Correlations of passive learning score with final grade in the four courses sampled.

What about specific study approaches that change between medical students and undergraduates, or between anatomy and physiology courses? Table 4.3 illustrates the type of course (anatomy or physiology) is more predictive of differences in study habits than educational level (MS1 or undergraduate). This finding follows

Gurung and Schwartz (2009) and Husmann et al. (2016) who suggested that course content is a stronger predictor of student study methods than any intrinsic factor in the student population. The lack of apparent difference between MS1 and undergraduates may be explained by the relatively small difference in their educational levels. Medical students are often treated as fundamentally different from undergraduates, but they have four years of undergraduate study patterns to draw from, and are unlikely to have learned to study differently after only one semester of medical school coursework. Additionally, in all populations, the lowest grade quartile of students reported trying the most different study techniques. The top quartile of students used fewer study techniques more frequently, while those at the bottom used a lot of different techniques but spent little time on each one.

	Anatomy study techniques	Physiology study techniques
Undergraduates	Looking at figures (.38) Reading the text (.56)	Reading course notes(.48) Practice questions(.42)
Medical Students (MS1)	Looking at figures (.56) Reading the text (.68)	Reading course notes(.52) Practice questions(.76)

Table 4.3- The most popular study techniques in each course. The numbers in parentheses indicate the percentage of students who reported 'frequent' or 'very frequent' use of the indicated study technique.

The third factor identified in the exploratory factor analysis was self-efficacy. While this factor only explained a small part of the sample variance, the correlations among the measures of self-efficacy were very high. The survey questions "I have studied enough," and "Expected grade" were strongly correlated with each other, and also strongly correlated with the student's actual grade in the course. Table 4.4illustrates the correlation of "I have studied enough" and grade.

	Anatomy	Physiology
Undergraduates: "I have studied enough"	$r^2 = .368$	$r^2 = .114$
Medical Students (MS1) : "I have studied enough"	$r^2 = .073$	$r^2 = .134$

Table 4.4- Among the strongest correlations in the sampled courses were between students perceptions of readiness and their actual grade. In some cases, the correlations are moderate or weak, but the measures of self-efficacy were better predictors of success than any single study technique.

The self-efficacy variables were among the strongest correlations in all student samples. Among the four courses, the anatomy undergraduates were best able to predict their course performance, as seen by the correlations in Table 4.4 This finding may be an artifact of sample size, a consequence of instructional methods used in the course, or it may point to underlying differences in the student populations. The physiology undergraduates overestimated their performance, as has been demonstrated in multiple studies, 'the illusion of competence' (e.g.,Kruger and Dunning 1999, Karpicke et al. 2009, others papers citing metacognition listed in chapter 2). Interestingly, the medical students, in both courses, tended to underestimate their readiness, and inversion of the frequently seen pattern in undergraduates, but one that has been observed before (Blanch-Hartigan 2011).

Discussion

The stated goal of this project was to determine what students are actually doing with their study time. Students in all of the sampled courses are sometimes advised about ways to improve their studying (Appendix C), but there were no data examining what the students were really doing. Typical advice given to students suggest using active learning and self-quizzing to prepare for exams. This project showed that students use a wide variety of study skills, with passive approaches (including reading the textbook, reading course notes, and reviewing diagrams) being among the most frequently used in all courses. Active learning approaches have been shown to be more effective learning strategies, but passive study habits tend to be used more frequently (Biggs 2001, Drapkin et al. 2015, Freeman et al. 2014, Pickering 2014, Prince 2004, Sweeney et al. 2014). Practice exam questions were frequently used by both levels of physiology students, a study habit that has been shown to be very effective, and improve metacognitive awareness (Karpicke et al. 2009). Interestingly, the physiology students had lower self-efficacy scores than the anatomy students, despite using a study technique (practice exam questions) that is supposed to improve metacognition (and self-efficacy). This contradiction may be due to differences in the method of examination in the two courses, differences in the students, or inaccurate reporting on the surveys. The current dataset is unable to answer this question.

While practice questions were used frequently in some of the courses, the most popular techniques across all courses tended to be very passive. This is not surprising, as passive learning techniques require the least effort, and can lead to acceptable grades when deep learning is not required (Biggs et al. 2001). The use of passive approaches contradicts the advice of instructors, and was shown to be slightly correlated with poorer course performance, a trend evident in all four courses sampled.

A subordinate goal of this project was to determine which, if any, study methods led to higher scores on exams. In that goal, the results were inconclusive. There were no statistically significant differences in study habits employed by the higher-scoring students. However, some trends can be observed, with active learning approaches being weakly positively correlated with course grade (Figure 4.1). Interestingly, the students who used the widest variety of study skills tended to be the lower-scoring students. This may represent a sampling bias, or may represent the idea of "grasping at straws." A student without a well-focused study plan may try a little bit of everything, without ever finding a truly effective study approach.

Another surprising finding in this dataset was in the measures of self-efficacy. Students in the sampled population could accurately predict their exam grades, and were able to honestly report when they felt well prepared for an exam, but this effect was strongest in only one of the four courses (anatomy undergraduates

A215). Medical students tended to underestimate their grades, perhaps due to the stresses of medical school courses, and the surveys being conducted near the beginning of their medical school careers. The MS1 students may simply have felt unprepared for their exams based on their patterns of undergraduate studying (Blanch-Hartigan 2011).

It was also found that anatomy and physiology students did not study in a significantly different way. While whole-class averages indicated that the most popular study techniques differed between the two courses, the overall study patterns taken by individual students did not change much. That is, passive learning patterns persisted in all courses, regardless of subject matter or educational level.

This pattern of passive learning may represent a strategic approach (Biggs et al. 2001) taken by students who understand that the exams in both courses are multiple choice, and passive study approaches are often adequate for multiple-choice exams. Active learning approaches may be viewed as a less efficient when the student knows that a deep knowledge of the material is not required on an exam that only assesses lower-level thinking.

The findings of this project have direct pedagogical implications, indicating that instructor advice on student study skills should be changed. Rather than advocating continued use of active learning only, instructors should encourage students to choose a few specific study skills (Barger 2012, Barger and Husmann 2013, Husmann et al. 2016). A reliance on a few study skills, used frequently, appears to lead to higher course grades, than using a lot of study skills infrequently.

Having established how students study (Research questions 1-3), the following chapter will examine research questions 4-6, visual approaches to studying.

CHAPTER 5: Visual Study Skills in Anatomy

Visual literacy and spatial ability are two different, but related, skills involved in understanding the visual world (Avgerinou and Ericson 1997, Bodner and Guay 1997, Meneghetti et al. 2011, Meneghetti et al. 2016). Spatial ability has long been understood as a correlate with success in STEM fields (discussed in Chapter 2 and Chapter 6), but visual literacy in STEM has not been well studied (Backhouse et al. 2016, Bardes et al. 2001, Bell et al. 2014, Boudreau et al. 2008, Naghshineh et al. 2008). Efforts to teach visual literacy in STEM fields include (Backhouse et al. 2016, Bardes et al. 2001, Bell et al. 2014, Pickering 2014), but measuring visual literacy attainment is still a challenge. All of the above citations used works of fine art to teach medical students clinically-relevant observational skills, but only Naghshineh et al. (2008) developed a measurement of visual literacy. To measure visual literacy, Naghshineh and colleagues introduced first-year medical students to the practice of carefully observing works of art, then made a quantitative measure of the number of specific observations those students made during clinical exams. It was found that students who had participated in the art observation training made significantly more clinical observations than their peers who did not receive any specific training in observation skills.

This study (Naghshineh et al. 2008) is the only one with any kind of assessment of student visual literacy in STEM. Other publications dealing with visual literacy in STEM have shown students to derive benefit from visual literacy training, but these benefits are all based in student attitudes and do not contain measurable improvements (Backhouse et al. 2016, Bardes et al. 2001, Bell et al. 2014).

Assessment of visual literacy has been recognized as a problem since the term was introduced in 1969 (Avgerinou and Ericson 1997, Perkins 1994, Wiles 2016). Measuring the number of clinical observations studetns make is a good way of assessing visual literacy skills, but it is time consuming and impractical in pre-clinical students. Chapter 2 summarizes the history of visual literacy research, but a brief recapitulation follows.

Visual literacy (VL) is the ability to meaningfully interpret static and dynamic images, and has a long and contentious history (Avgerinou and Ericson 1997). Despite the simple, one-line definition for visual literacy given above, it is a complicated and wide-ranging topic that has resisted a firm definition for the last fifty years.

Very little has been written about visual literacy in anatomy or biology, but several revealing publication in biochemistry discuss visual literacy (Anderson 2007, Linenberger and Bretz 2015, Schonborn and Anderson 2006 , Schonborn and Anderson 2010, Serpente 2016, Wiles 2016). The existence of visual literacy discussion in biochemistry may be due to the necessity of creating meaningful mental representations of biochemical entities in the study of biochemistry. Biochemical entities are mostly molecules and proteins, impossible to actually visualize with a microscope, so conceptual visual models are the only visual representations available to student of biochemistry. The variety of representational schemes for biochemical entities is also mentioned as a need for robust VL education in biochemistry (Wiles 2016). That is, a protein, for example, can be represented by a linear arrangement of letters corresponding to amino acids, a 3D ball-and-stick model, or a 3D ribbon diagram. Each of these visual representations of the protein conveys different information, and the biochemistry expert is able to extract the information of the image, and even infer the appearance of one type of image from another type of image (Schonborn and Anderson 2006). In 2010 Schonborn and Anderson continued their work in VL and defined a list of skills the visually literate biochemistry students should have, termed 'reasoning with images' in the original. The list of skills involved in reasoning with images includes:

- Decode the symbolic language composing an image
- Evaluate the power, limitations, and quality of an image
- Interpret and use an image to solve a problem
- Spatially manipulate an image to interpret and explain a concept
- Construct an image to explain a concept or solve a problem
- Translate horizontally across multiple images of a concept
- Translate vertically between images that depict various levels of organization and complexity
- Visualize orders of magnitude, relative size, and scale.

Outside of discipline specific literature, The Association of College and Research Libraries (ACRL) who released a set of standards for VL in October 2011 (Hattwig et al. 2013). The ACRL standards defined a series of seven competencies designed to show what a visually literate person can do. Assuming each of the competencies is met, one can be called 'visually literate'. The ACRL list still contains very little detail on how to assess each competency, but it provides a theoretical foundation for further inquiry in VL research. The ACRL list has some similarity with the biochemistry list above, and both were incorporated to create a list of VL competencies for anatomy students described below.

1. Determine the nature and extent of the visual materials needed
2. Find and access needed images and visual media effectively and efficiently
3. Interpret and analyze the meanings of images and visual media
4. Evaluate images and their sources
5. Use images and visual media effectively
6. Design and create meaningful images and visual media
7. Understand many of the ethical, legal, social, and economic issues surrounding the creation and use of images and visual media, and access and use visual materials ethically

Elaboration of each competency can be found in chapter 2.

The following table prepared by the dissertation author (Table 5.1) uses the ACRL list of visual literacy competencies as its base, but includes some of the specific skills defined by the work of biochemistry educational researchers. While rigorously assessing visual literacy is still a challenge, the following list of anatomy-specific visual literacy competencies provides a theoretical framework for discussing what the visually literate anatomy student can do.

Primary visual literacy skills needed by anatomy students	**Competencies included in each primary skill**
1. Interpret and analyze the meanings of images	b. Decode the conventions and design elements used in anatomical illustration c. Understand the scale of the image d. Compare two images of the same object presented in different modes e. Compare two images of the same object from different angles
5. Evaluate images for their strengths and weaknesses	a. This should include textbook photographs, illustrations, and medical imaging
6. (Use existing images and visual media to communicate effectively)	a. Rarely do anatomy students (in the sample populations) have the opportunity to use images to communicate
7. (Design and create meaningful images and visual media)	a. Image creation is the highest goal of visual literacy and may not be practical to teach the conventions of image creation in anatomy courses

Table 5.1- A list prepared by the dissertation author of the visual literacy skills anatomy students need to learn from images and effectively communicate with

images. Skills 3 and 4 are enclosed in parentheses because they are goals of visual literacy education, but may be outside the scope of most anatomy courses.

Having created a theoretical basis for understanding visual literacy in anatomy, the next step was to examine how visual literacy is actually employed by students.

The research project discussed here (facet 2: “Visual literacy in anatomy”, of the original research outline in Chapter 1) was designed to answer the following questions (see also Table 5.2):

Research Question 4: How often do anatomy students use visual study skills?

This question is the central idea guiding the overall research plan. The following questions are all further elaborations of the visual study skills question. The introduction and literature review chapters (Chapters 1 and 2) are full of justifications and research explaining the utility of visual learning (especially mental rotation and spatial ability) in a variety of fields, including other sciences, and anatomy, but the use of visual study skills in novice students has not been fully explored in the existing literature (to clarify, mental rotation and spatial ability are well explored in the existing literature, but the use of visual study skills, as defined in this dissertation, Chapter 1, subheading “Definitions” is not widely reported) (Backhouse et al. 2016, Bardes et al. 2001, Bell et al. 2014, Boudreau et al. 2008, Naghshineh et al. 2008).

Research Question 5: Are there differences in student self-reported visual learning measures?

More specifically:

c. **Do students who self-report a preference for visual learning use visual study skills more often in their anatomy courses?**
d. **Do students who self-report a preference for visual learning do better in anatomy course performance metrics?**

This question was designed to look at differences in student perceptions and uses of visual learning in anatomy. That is, do students use visual study strategies frequently, if so which kind of students (those who self-report as visual learners, or not), and do these strategies correlate with course grade? Students enter anatomy courses with a wide variety of previous experiences, and it is unclear how those experiences shape a student's study habits. This question asks whether different students use different study habits without any intervention from the instructors or researchers.

Research Question 6: Do student study habits for anatomy change during the semester?

All of the previous questions rely on sampling students at a single time point in the semester. This question allows for the exploration of study habit changes in students during a course, including those habits related to visual learning and spatial ability. It has been suggested in some visual literacy literature (Orion et al. 1997, Titus and Horsman 2009) that simply taking a science course can lead students to changes their habits and increase their visual literacy abilities. As students navigate the challenges of a course, and experiment with new ways of learning, they may change their study habits, without any specific suggestions from instructors.

Facet	Populations Examined (Chapter 3)	Main Research Question (Chapter 3)	Subordinate Research questions	Chapter
1. Study Skills Survey	A215 P215 A550 P531	What study methods do students use?		4
2. Visual study skills	A215	Do students use visual study methods?	Does the use of visual studying change during the course?	5
3. Mental Rotation	A215	How much spatial ability do students have?	Does spatial ability change during the course?	6
4. In-Class Drawing	A215	Does the use of in-class drawing lessons improve SA or VL?		7
5. Web-based video tutorials	Various	Does the use of web-based drawing tutorials improve SA or VL?		8

Table 5.2- The relationship between research questions and the individual facets of the larger research plan.

Methodology

To answer the research questions listed above, a survey (Appendix A) was developed to assess students' self-reporting of visual study strategies. This survey tested only anatomy undergraduates (and specifically, students in Anatomy A215, see chapter 3). Because there are no established assessments for measuring visual literacy, it was assumed that use of visual study strategies was a good estimator of visual literacy. This assumption was based on the anatomy-specific list of visual literacy competencies (defined above). If students possess the competencies, it was expected that their study habits will align with the competencies, and they will employ more visual study strategies (e.g., looking at textbook images, drawing their own images or tables,).

The survey used to examine visual study strategies included 16 questions about the frequency of use of a variety of study skills, and 7 questions about the students' self-perception as a visual learner. The survey may be seen, in full, in Appendix A.

An additional feature of the survey used in this facet of the dissertation was the inclusion of questions relating to learning style (the 7 questions about the students' self-perception as a visual learner). Learning styles are a controversial topic with numerous authors for and against their validity in educational research (e.g., Fleming et al. 2006, Leite et al. 2010, Lujan et al. 2006). Learning styles will be discussed further in the discussion section. The learning style inventory used here consisted of seven VARK-like questions related only to the visual axis of the VARK. (e.g., "if I am planning a route to a new location, I like to look at a map," If I am planning a presentation, I create an outline first," "I consider myself a visual leaner."). The inclusion of a learning style inventory was necessary for two reasons. First, does a student's self-perception of learning style have any impact on course performance? Second, does self-perception play a role in how a student chooses to study?

Surveys were deployed to anatomy (A215) undergraduates at the beginning and end of the semester, using the same IRB protocol from the earlier project (see Appendix A for survey details and Appendix D for IRB details). Students were surveyed near the beginning of the course (before the first set of lecture and lab exams, approximately three weeks into the semester) and near the end of the course (before the final lecture exam, approximately one week before the end of the semester). These two survey time points were chosen to assess the study habits of novice students (before they have had any examination experience) and more experienced students to see if their study habits changed after exposure to course material and examinations.

The collected data were again entered into a database (Excel, Microsoft 2010) and analyzed using SPSS 21.0 (IBM 2012). A correlation matrix was created to explore the survey responses with the strongest correlations to final grade. Latent variables were pulled from the data using an exploratory factor analysis as a way of finding which study skills and demographic traits naturally clumped together in the dataset. These latent variables were then correlated (bivariate or Pearson correlations) with final grades to find the most effective study strategies. The VARK-style questions all had high loadings on a single factor, so these variables were combined into a new score called 'visual preference.' Visual learning strategies ('made my own tables,' 'made my own drawings,' 'looked at textbook images') also shared high loadings with a separate factor which is termed "visual learning." Because student survey data were collected at two different time points in the semester, this dataset was also used to analyze research question 6, "do study habits change during the semester?" For this analysis, paired student responses (from the early- and late-semester surveys) were compared using t-tests to see if the student population (as a whole) showed any significant changes in study habits as a result of their enrollment in an anatomy course.

Results

Students reported frequent use of visual study skills, with whole class averages on the visually oriented survey questions indicating 'frequent use' of visual study skills. This indicates some familiarity with visual literacy. If the students are visually literate, we should expect to see them using visual study habits frequently

Class averages for use of visual study skills decreased during the semester, but the average measure of 'visual preference' increased (Figure 5.1).

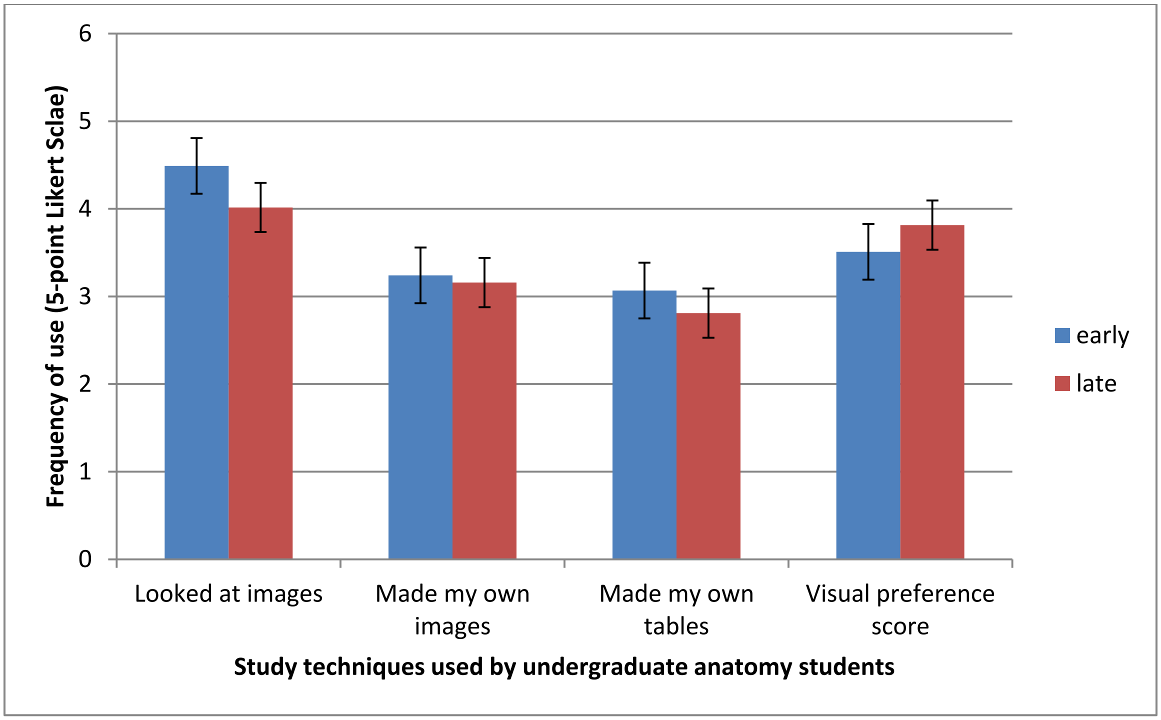


Figure 5.1- Comparison of early- (in blue) and late-semester (in red) visual learning class averages (n=163).

The next series of graphs takes the above measures of visual literacy (visual study skills scores, and visual preference score) and correlates each with final course grade. Remember, the exploratory factor analysis found a natural grouping of visual learning variable, so all of those (looking at images, making images, making tables) have been grouped as a single variable (termed 'visual learning score') in the following figures. Figure 5.2 shows the correlation ($r^2 = 0.035$, p=0.78) between visual learning score and final grade, showing that successful students were equally likely to use a lot of visual learning, or very little.

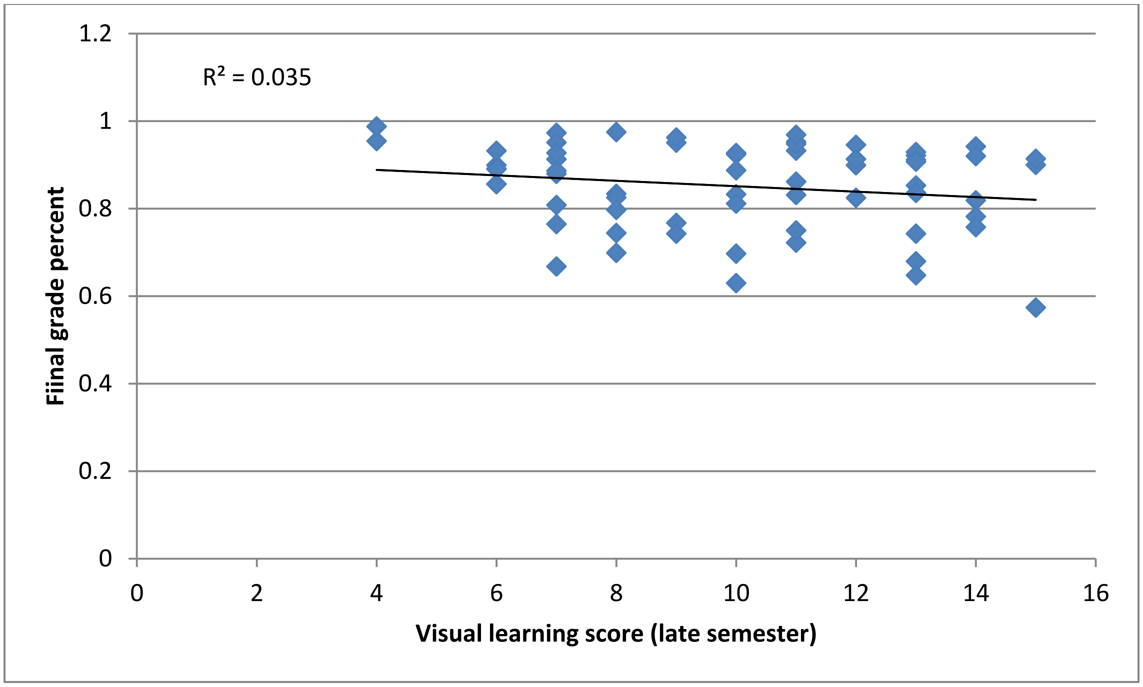


Figure 5.2- Correlation of visual learning score and final grade in anatomy (A215) undergraduates. Visual learning score did not correlate ($p=0.78$) with final grade, but a slight negative trend was observed.

Figure 5.3 illustrates the correlation between visual preference score and final grade. While the fit of this line shows no significant trend ($p=0.66$) in the data, higher performing students may have a slightly higher visual preference score.

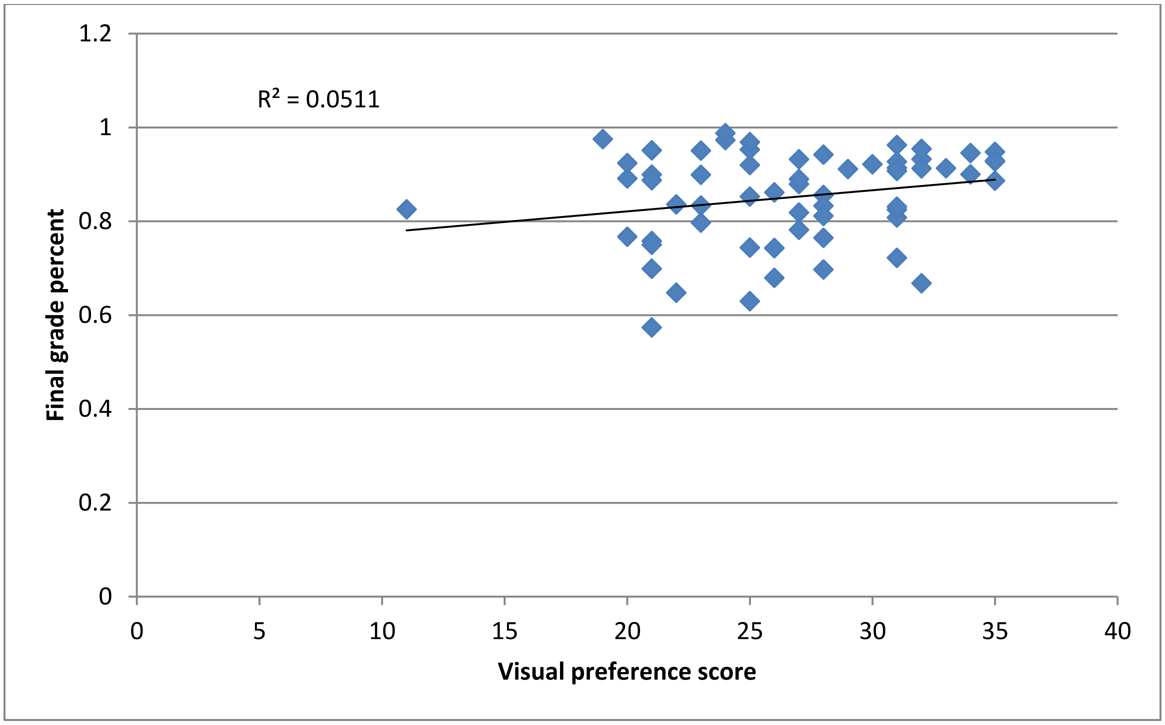


Figure 5.3- Correlation of visual preference score and final grade in anatomy (A215) undergraduates. While there is no statistically significant (p=0.66) correlation between final grade and visual preference, the slope of the line indicates a slight trend in that direction.

Figure 5.4 shows the correlation (or lack thereof) of visual preference and visual learning. Interestingly, a preference for visual learning does not correlate with frequent use of visual study habits (r^2=.0086, p=0.94).

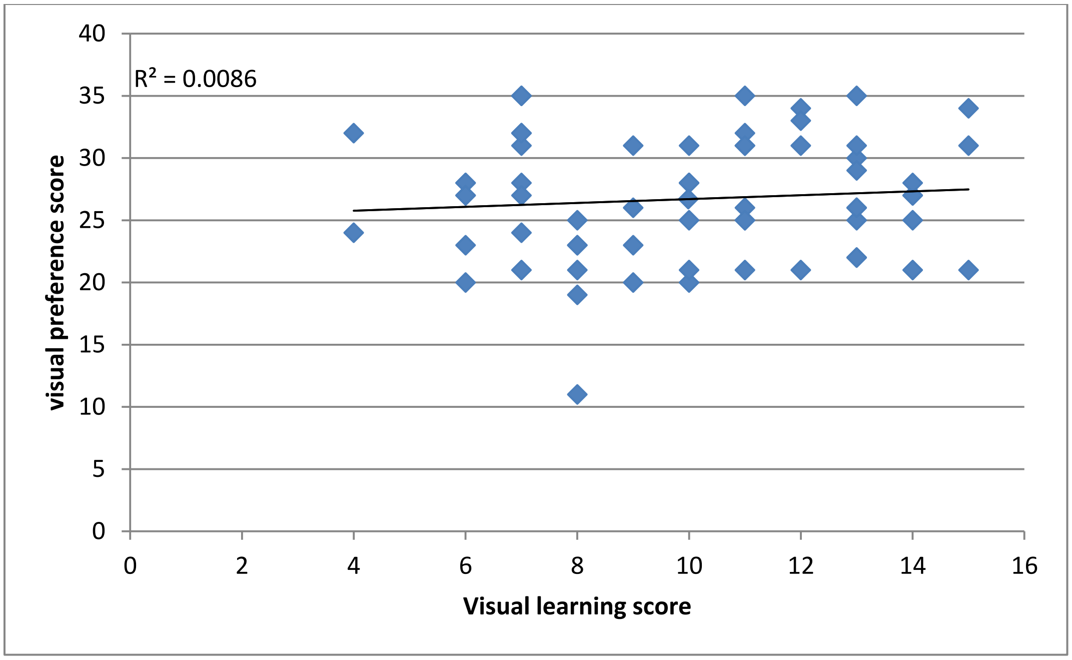


Figure 5.4- There is no statistically significant correlation (p=0.94) between visual preference score and use of visual learning skills in anatomy (A215) undergraduates.

Discussion

This facet of the dissertation was designed to examine student use of visual learning during an anatomy course, and answer the following questions:

Research Question 4: How often do anatomy students use visual study skills?

Research Question 5: Are there differences in student self-reported visual learning measures?

a. **Do students who self-report a preference for visual learning use visual study skills more often in their anatomy courses?**

b. **Do students who self-report a preference for visual learning do better in anatomy course performance metrics?**

Research Question 6: Do student study habits for anatomy change during the semester?

It was found that visual study skills were used frequently by the whole class, but they tended to be lower-level visual literacy skills (as described in table 5.1) (e.g., looking at a book image rather than drawing a new image). Students report understanding and appreciating the need for visual literacy (Bell et al. 2014), but the students in this dissertation sample were only using the lowest levels of visual literacy (looking at images). The use of higher-level visual literacy skills may be inaccessible to students who have not had specific instruction in these skills (Hattwig et al. 2014). Much like in verbal literacy where reading precedes writing, creating images is a higher-level skill than 'reading' an image, and many students will not have the necessary background to understand how to create meaningful images from which to study anatomy content.

Learning style has received a lot of attention in the educational research literature (for an attempt to create a guiding thematic principle for learning style inventories, see Hawk and Shah 2007, for others attempting to validate learning style inventories see Davidson and Richie 2016, Fleming and Baume 2006, Ganesh 2014, Leite et al. 2010, Yazici 2016). The research in this dissertation facet indicates that a self-reported preference for visual learning has no correlation with course outcomes, or the student's preferred study method. That self-reported visual learners are equally likely to be high- or low-scoring anatomy students is not surprising given Ganesh (2014) who reported no differences in students' outcomes on a series of university exams and learning styles.

What is surprising is that self-reported visual learners do not necessarily use visual study skills more frequently than students with a low visual preference. This may be related to the problems inherent in measuring learning style preferences (Farkas et al. 2015, Leite et al. 2010, Riener and Willingham 2010), or it may be related to assessment methods used in the sampled course. Student with a high visual preference may prefer to study visually, but have found through their experiences in anatomy that visual studying may not be beneficial, given the written nature of lecture exams. Although lab exams are visual in nature, lab exam questions are simple identification (the lowest level of visual literacy) and success on lab exams may not require higher-level visual literacy or spatial ability, limiting the utility of visual studying, even for students with a high visual preference.

The results of the visual study skills survey confirm that visual study habits do change during the course (Question 6). Whole-class averages of visual learning habits decreased during the semester, but so did reported use of all study skills. These findings may indicate that students had a better idea of how to study and therefore were simply using fewer different study strategies as the semester progressed. The decrease in frequency of use of visual study skills may also be a natural part of all courses as motivation decreases during the semester. While self-reported hours of studying did not decrease, the reported frequency of each study habit did decrease. This may indicate student use of techniques not listed on the survey, or an inaccurate reporting of their use.

The visual study skill that decreased least was “made my own images.” This may indicate that students who make drawings find them to be the most useful study strategy. Other possible explanations are from non-cognitive variables, namely motivation (Robbins et al. 2004). Motivation has been shown to be strongly correlated with college success and retention, and typically students using the most active learning (such as making drawings) are the most motivated (Aleven and Koedinger 2000).

Individual student visual preference (the combined variable based on the VARK-style questions in the survey) increased during the semester, based on comparisons of early semester and late semester surveys. This finding may indicate that students are gaining an appreciation for visual studying, even though their actual use of visual study methods decreased (Figure 5.1). Use of all study methods (including visual ones) decreased during the semester, but self-reported preference for using those methods increased.

Fewer students completed the late-semester survey (n=63, as compared to the early semester survey n=127) so the results may also be an artifact of sampling bias. However, if it is a sampling bias that does indicate that the students with the greatest preference for visual studying were more likely to be present during the final days of the semester, a possible correlation with the results indicating visual learners excel in STEM fields (McGrath and Brown 2005).

CHAPTER 6: Mental Rotation

Visual literacy and spatial ability are two different, but related, skills involved in understanding the visual world (Avgerinou and Ericson 1997, Bodner and Guay 1997, Meneghetti et al. 2011). Spatial ability has long been understood as a correlate with success in STEM fields (discussed in Chapter 2), but visual literacy in STEM has not been well studied (Backhouse et al. 2016, Bardes et al. 2001, Bell et al. 2014, Boudreau et al. 2008, Naghshineh et al. 2008). Chapter 6 deals with spatial ability in anatomy students. For more details on visual literacy, see chapter 5.

Since cognitive science first explored the issue of spatial ability, it has been seen to be strongly correlated with success in science fields (Carp and Silberman 1969, Culver and Dunham 1969, McGee 1979). The exact causal relationship of this correlation is still poorly understood, but there is an increasing body of literature suggesting that teaching spatial ability can lead to improved success for students in STEM fields (Beck et al. 1978, Boudreau et al. 2008, Canty et al. 2015, Fuks et al. 2009, Garg et al. 2001, Hegarty et al. 2009, Hoyek et al. 2014 , Keehner et al. 2006, Langlois et al. 2014, Lufler 2012, Lufler et al. 2012, Luursema et al. 2008, Nicholson et al. 2016, Nugent et al 2012a, Nugent et al. 2012b, Pahuta et al. 2012, Provo et al. 2002, Sweeney et al. 2014, Wanzel et al. 2002).

Spatial ability is often defined as the ability to mentally manipulate two- and three-dimensional images (Bodner and Guay 1997, Meneghetti et al. 2011, Meneghetti et al. 2016). A variety of cognitive science sources have further explored spatial ability and have defined a number of different sub-categories within spatial ability

(Meneghetti et al. 2016). However, the new cognitive definitions have been slow to permeate the discipline specific literature, and most STEM educational researchers still treat spatial ability as single entity. Spatial ability can be tested in a variety of ways including polyhedral net folding, aperture passing, and cube counting. There appears to be a consensus that mental rotation plays a role in all of these facets of spatial ability, so mental rotation is often treated as a close proxy for spatial ability as a whole (Meneghetti et al. 2016).

Over the past 80 years, spatial ability has been frequently assessed in anatomy students (both undergraduates and medical students) with a broad consensus that spatial ability correlates strongly with course performance. Most recent publications in the spatial ability of anatomy students focus on teaching spatial ability through a variety of pedagogical interventions. These interventions include passive learning (Vorstenbosch et al. 2013), 3D computer based models (Ruisoto et al. 2012, Ruiz et al. 2009, Garg et al. 2001, Pickering 2014, Roach et al. 2016), animations (Ruiz et al. 2009, Evans 2011), Drawing (Ruiz et al. 2009), 3D images (Luursema et al. 2008), anatomical cross sections (Provo et al. 2002), and surgery simulations (Keehner et al. 2006, Roach et al. 2012), and all have shown some success in improving students' spatial ability scores. However, improving anatomy grades through improving spatial ability has been less frequently demonstrated.

Knowing that spatial ability correlates with student success in STEM fields (including anatomy), the following research project was initiated to test the spatial ability scores of anatomy undergraduates at Indiana University. Mental rotation was used as an easily tested proxy for the entire suite of factors included in spatial ability (Meneghetti et al. 2016).

The research in this chapter was organized to answer the following research questions:

> **Research Question 7: Do undergraduates enter an introductory anatomy course with adequate mental rotation skills (MRT scores)?** More specifically:
>
> a. **Do mental rotation (MRT) scores change during the semester?**
> b. **Do mental rotation scores change, given specific instruction in anatomical drawing?**
> c. **Do mental rotation scores correlate with anatomy course performance metrics?**

Previously published literature suggests mental rotation abilities (summarized in the spatial ability section of Chapter 2) of novice students can be highly variable (Faurie and Khadra 2012, Garg et al. 2001, Keehner 2011, Keehner et al. 2008, Ruisoto et al. 2012, Ruiz et al. 2009, Vorstenbosch et al. 2013). In general, students rarely have enough experience with mental rotation (or similar spatial ability tasks) to have good MRT scores, which can make learning anatomical relationships more challenging (Boudreau et al. 2008, Codd and Choudhury 2011, Fuks et al. 2009, Garg et al. 2001, Hegarty et al. 2009, Keehner et al. 2006, Lufler et al. 2012, Luursema et al. 2008, Provo et al. 2002, Wanzel et al. 2002).

Table 6.1 visually highlights for the reader which specific facet was used to answer the research question about spatial ability

Facet	Populations Examined (Chapter 3)	Main Research Question (Chapter 3)	Subordinate Research questions	Chapter
1. Study Skills Survey	A215 P215 A550 P531	What study methods do students use?		4
2. Visual study skills	A215	Do students use visual study methods?	Does the use of visual studying change during the course?	5
3. Mental Rotation	A215	How much spatial ability do students have?	Does spatial ability change during the course?	6
4. In-Class Drawing	A215	Does the use of in-class drawing lessons improve SA or VL?		7
5. Web-based video tutorials	Various	Does the use of web-based drawing tutorials improve SA or VL?		8

Table 6.1**-** The relationship between research questions and the individual facets of the larger research plan.

Methodology

This project was designed to answer research questions 7a and 7c, namely "do students have adequate mental rotation skills in anatomy, and do those skills translate to course performance?" Project 3 used the same survey (appendix A) and IRB protocol (Appendix B) as Project 2, with no additional changes to the survey.

An additional test of mental rotation ability was also given to students in conjunction with the basic survey. The mental rotation test (MRT) was originally designed by Bodner and Guay (1997) for use with chemistry students, but use of mental rotation tests is well-established as a proxy for spatial ability in the educational literature (Chatterjee et al. 2011, Lufler et al. 2012, Meneghetti et al. 2016). The MRT contains 20 questions which ask the participant to mentally manipulate a 2-dimensional drawing of a 3-dimensional, geometric object. Each question consisted of an example rotation of one object. The participant must then reproduce in a new object, via analogy, the same rotation from the example, and choose the correct answer from a multiple-choice list of four options. The final score on the test was calculated out of twenty points, based on the number of correct answers. The test was timed with ten minutes being allotted for completion. Incomplete items were scored as incorrect.

Individual MRT scores for the whole class were then averaged, and individual students were divided into a high-MRT and low-MRT score group, separated by the median score. The high- and low-MRT variable was then introduced into a correlation matrix with the other survey variables (as above) to examine which factors most strongly correlated with MRT scores. MRT scores were also correlated with final grade to answer research question 7c.

The course sampled was an undergraduate anatomy course (A215) described in the earlier methodology chapter 3, subheading student populations.

Students were given the MRT at the beginning of the course (before the first exam, approximately three weeks into the semester) and before the final exam, approximately one week before the end of the course. Because MRT scores were collected at two time points in the semester, changes in whole-class performance were analyzed using a paired t-test to look for statistically significant changes in MRT scores during the semester of anatomy.

The high- and low- MRT groups did not have any *statistically significant* correlations with grade or preferred study skills. The following graphs illustrate the *slight* trends for students with high spatial ability to prefer visual study methods.

Results

Figure 6.1 shows the change in MRT score from the early- to late-semester time points. MRT scores increased slightly, but non-significantly (p=0.13).

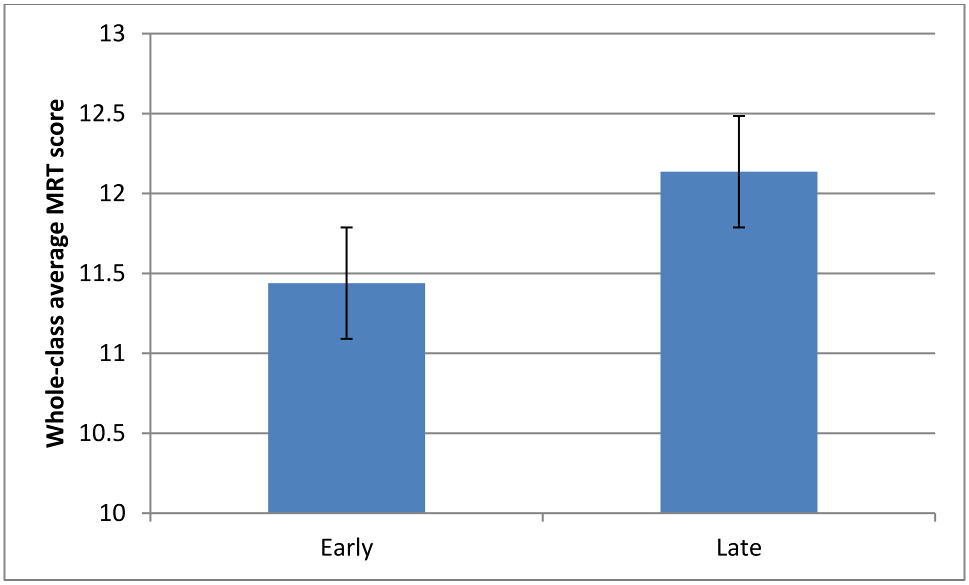


Figure 6.1- Mental rotation test scores (MRT) as assessed early and late in the semster of undergraduate anatomy (A215). Columns represent whole-class averages, and were not significantly different (p=0.44).

Figure 6.2 illustrates the correlation between late-semester MRT and final course grade. A very small positive correlation was seen between these two variables, but the scatterplot shows a large number of students with high grades and low MRT scores (those data points above the trend line).

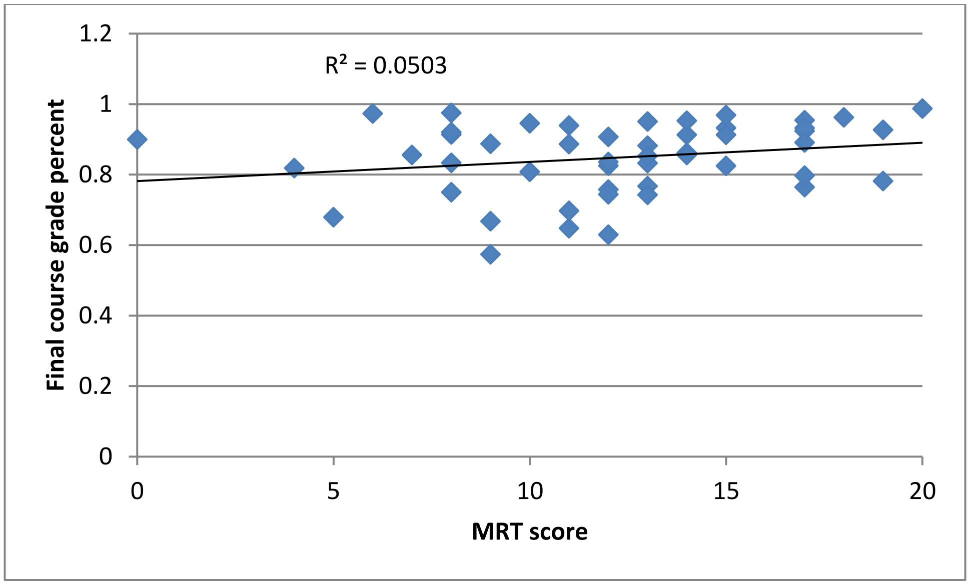


Figure 6.2- The correlation of use of final course grade with mental rotation test score (MRT) in undergraduate anatomy (A215). Results were not statistically significant (p=0.57)

Figure 6.3 compares late semester MRT to late-semester visual studying. The survey contained 26 questions about specific study habits may use to prepare for anatomy exams. Four of those items were identified by an exploratory factor analysis to be highly correlated with each other, and were combined into the single variable called ‘visual studying.’ The four ‘visual studying’ survey items included: “Looking at images in the text book,” “Making my own drawings,” “Making my own tables,” and “Making my own flashcards.” Based on the theoretical underpinnings of visual literacy research (see chapter 2) it is thought that the visual studying variable is a reasonable proxy for visual literacy, and MRT is a measure of spatial ability. Figure

6.3 shows that those two parts of understanding the visual world are not correlated in the sample population.

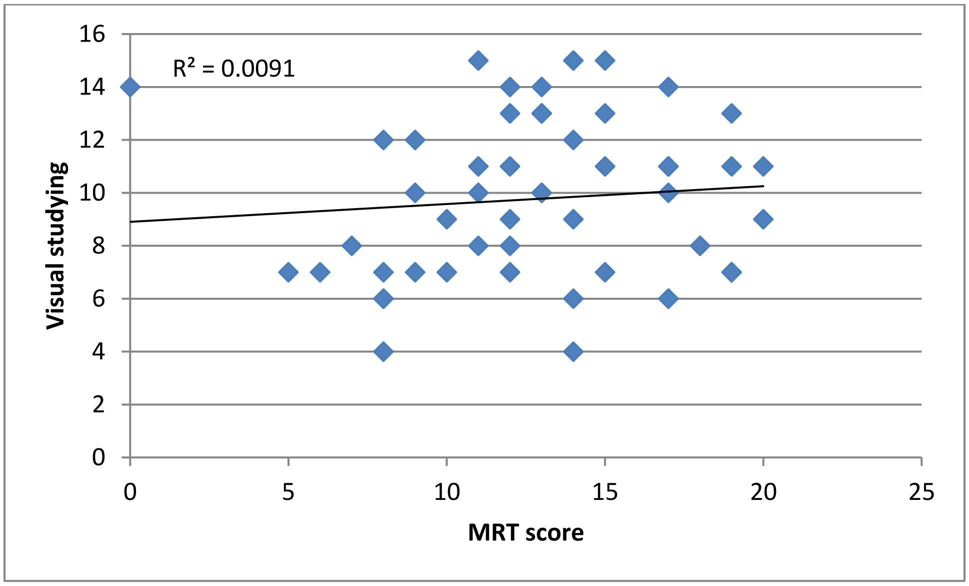


Figure 6.3- The correlation of use of visual study skills with mental rotation test score (MRT) in undergraduate anatomy (A215). There was no significant correlation between use of visual study approaches and MRT score (p=0.91).

Figure 6.4 correlates MRT with a preference for visual studying. Visual studying preference was assessed using seven survey questions related to a students preferred way of learning new material. Those seven questions included:

1. When learning something new I will look at pictures and diagrams first.
2. When planning a route to a new place, I prefer to look at a map.

3. When giving directions to a friend, I would prefer to draw a map.
4. If a physician is explaining a medical diagnosis, I would prefer to see a picture or model of the problem.
5. When planning a speech or paper, I use an outline.
6. When delivering a speech I prefer to use pictures and diagrams to explain key points.
7. I believe I am a visual learner

MRT was not significantly correlated with visual preference, but again, a small trend may be present in the data.

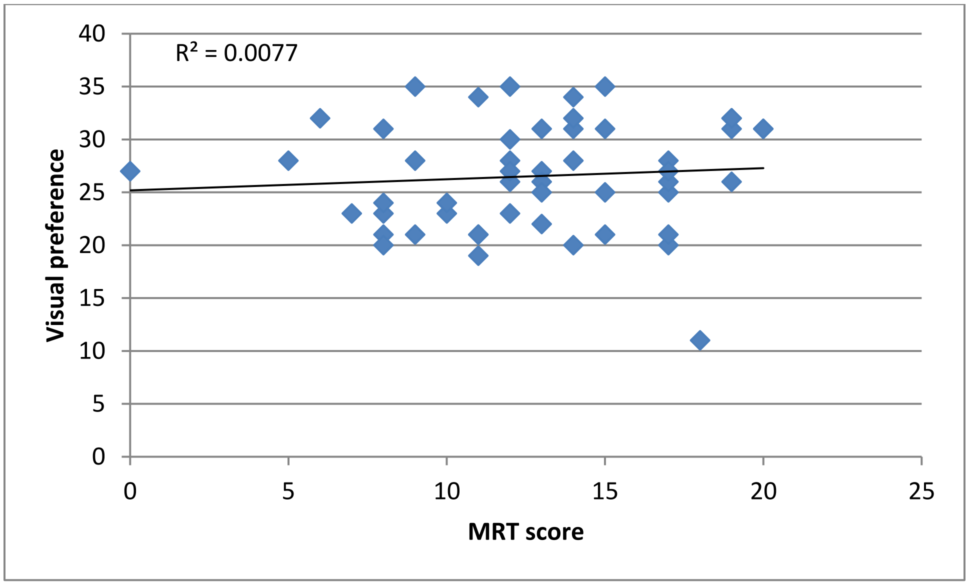


Figure 6.4-The correlation of use of visual preference with mental rotation test score (MRT) in undergraduate anatomy (A215)

Discussion

Mental rotation score was found to increase slightly while taking an undergraduate anatomy course (Anatomy A215), with no specific instruction in visual approaches to learning or training in spatial ability. That is, passive acquisition of spatial ability may occur simply through the act of taking an anatomy course. This result has been seen with spatial ability in other fields, notably in geology (Titus and Horsman 2009) and anatomy (Vorstenbosch et al. 2013).

Gender differences in spatial ability are a contentious topic (see chapter 2) with various sources supporting and denying the existence of gender differences in spatial ability (Hyde 2016, Moe 2016, Quaiser-Pohl et al. 2016, Voyer et al. 1995, Williams and Meck 1991). The participants in the sampled population were 80% female (n=359), with comparable proportion of women completing all parts of the survey and mental rotation test (n=48). Gender differences were not examined in this research due to limited sample sizes and unequal distribution of men and women in the sample. Future directions for this research would involve larger sample sizes, so the populations could be subdivided by gender and any potential gender differences could be explored

Mental rotation scores were not found to significantly correlate with any other variable, including final grade, visual study skills, or preference for visual learning. The lack of correlation between MRT and use of visual study skills may be related to a variety of other factors including motivation (Robbins et al. 2004) , strategic studying (Biggs et al. 2001) , or authentic assessment (Hart 1994, Gurung and McCann 2011, Schwartz and Gurung 2012, Wiggins 1990), unconnected to a student's mental rotation ability. These factors are discussed in detail chapter 5.

The lack of correlation between MRT and visual preference is surprising. It was expected that those students with the strongest preference for using visual study skills would be naturally good at spatial ability. The lack of correlation here could indicate that self-reported preferences for a specific study skill are not truly indicative of a student's abilities. Additionally, visual learning preference is indicative of *visual literacy* and the MRT is indicative of *spatial ability*, two different ways of understanding the visual world (chapter 2, Kastens 2010). It may be that visual literacy and spatial ability are not strongly correlated, at least when measured in this population.

CHAPTER 7: In-class Drawings

In the previous two chapters, spatial ability and visual literacy of anatomy undergraduates were discussed. These two components of understanding the visual world have been shown to be important in anatomy education (e.g., visual literacy Backhouse et al. 2016, Bardes et al. 2001, Bell et al. 2014, Pickering 2014. Spatial ability- Beck et al. 1978, Boudreau et al. 2008, Canty et al. 2015, Fuks et al. 2009, Garg et al. 2001, Hegarty et al. 2009, Hoyek et al. 2014 , Keehner et al. 2006, Langlois et al. 2014, Lufler 2012, Lufler et al. 2012, Luursema et al. 2008, Nicholson et al. 2016, Nugent et al 2012a, Nugent et al. 2012b, Pahuta et al. 2012, Provo et al. 2002, Sweeney et al. 2014, Wanzel et al. 2002. For a full review of both concepts, see Chapter 2). Chapter 7 describes a pedagogical intervention designed to teach undergraduates spatial ability and visual literacy while they learn anatomy course content. Students were instructed in drawing anatomical structures in a series of lectures designed to emphasize the communication aspects of creating an image. Drawing by hand was chosen as the pedagogical intervention in this project for the reasons described in the following paragraphs.

A number of different methods to teach students spatial ability in anatomy have been described in the literature including: passive learning (Vorstenbosch et al. 2013), 3D computer based models (Ruisoto et al. 2012, Ruiz et al. 2009, Garg et al. 2001, Pickering 2014, Roach et al. 2016), Animations (Ruiz et al. 2009, Evans 2011), drawing (Ruiz et al. 2009), 3D images (Luursema et al. 2008), anatomical cross sections (Provo et al. 2002), and surgery simulations (Keehner et al. 2006, Roach et al. 2012) but often these rely on expensive software, complex computer models, or animations. While effective, these other methods are expensive or time-consuming.

Only one published article has measured visual literacy gains in anatomy students (Naghshineh et al. 2008), but this required numerous observational visits to an art museum, and lengthy interviews with each participant afterward.

Other fields have demonstrated the teaching of visual literacy (examples from biochemistry include: Schonborn and Anderson 2006, Anderson 2007, Schonborn and Anderson 2010, Wiles 2016, Serpente 2016, Linenberger and Bretz 2015). One specific method that has shown improvements in visual literacy is drawing by hand (Ainsworth et al. 2011, Dempsey and Betz 2001, Heuschele 1999, Lyon et al. 2013). Drawing by hand has been shown to improve spatial ability (Ruiz et al. 2009) and visual literacy (Ainsworth et al. 2011). It is also a frequently suggested study aid to struggling students (Gurung and McCann 2011, Van Meter and Garner 2005, course syllabi Appendix C), and has shown some improvements in student metacognition (Lyon et al. 2013, Van Meter and Garner 2005). Additionally, drawing is inexpensive, easy to demonstrate, and easy for students to do outside of class time. The only potential drawback to drawing is student resistance to the activity, often for fear of being judged on artistic merit (Dempsey and Betz 2001).

Drawing by hand therefore was chosen as the pedagogical intervention to aid students in learning spatial ability, visual literacy and anatomy content. To test the effectiveness of this intervention, the following research questions were used to organize this facet of the research:

Research Question 7: Do undergraduates enter an introductory anatomy course with adequate mental rotation skills (MRT scores)? More specifically:

a. Do mental rotation (MRT) scores change during the semester?
b. Do mental rotation scores (or visual literacy metrics) change, given specific instruction in anatomical drawing?
c. Do mental rotation scores correlate with anatomy course performance metrics?
d. Does participation in drawing lessons correlate anatomy course performance metrics?

Parts b. and d. of this larger question will be addressed by this chapter. Table 7.1 visually represents how the study facet (in-class drawing) relates to the overall research questions.

Facet	Populations Examined (Chapter 3)	Main Research Question (Chapter 3)	Subordinate Research questions	Chapter
1. Study Skills Survey	A215 P215 A550 P531	What study methods do students use?		4
2. Visual study skills	A215	Do students use visual study methods?	Does the use of visual studying change during the course?	5
3. Mental Rotation	A215	How much spatial ability do students have?	Does spatial ability change during the course?	6
4. In-Class Drawing	A215	Does the use of in-class drawing lessons improve SA or VL?		7
5. Web-based video tutorials	Various	Does the use of web-based drawing tutorials improve SA or VL?		8

Table 7.1- The relationship between research questions and the individual facets of the larger research plan.

Methodology

The first three projects previously explained in chapters 4-6 only collected data from students, without suggesting or implementing any changes in anatomy course instruction or explicit guidance to students about how to utilize visual literacy strategies when studying. While the researcher did not provide any explicit advice relating to visual or spatial studying in the above projects, instructors frequently advise students to use drawings as a study aid, and could not be controlled. For additional details on study suggestions made in anatomy courses, see APPENDIX C with sample syllabuses). In contrast, the research presented here deals with a specific pedagogical intervention to teach visual and spatial ability.

This project was created around a pedagogical intervention designed to actively teach students how to employ more visual skills in their studying. Project 4 looked at research questions 1-8, re-assessing the baseline study habits of anatomy undergraduates, testing their mental rotation ability, and teaching them ways to improve MRT scores and course grades. Institutional Review Board approval (exempt protocol) was granted (IU IRB#: 1301010307).

Project 4 used a quasi-experimental design in the anatomy undergraduate classroom involving two sections of the Anatomy A215 class (class details in Methodology Chapter 3). In spring of 2013, the anatomy course was taught as two separate sections, with identical course goals, labs, and exam formats. Minor differences in syllabus and specific exam questions were ignored because previous versions of this course had shown student outcomes to be the same. One section of the course was taught in the traditional way with only didactic lectures, while the other section incorporated a series of visually-focused lectures in which students drew anatomical objects along with the instructor. The visually-focused lecture covered the normal anatomy content of the course, but used student-produced drawings as a supplement to the provided anatomical images. Six visual lectures were delivered on the topics of bone development and anatomy, skin histology, renal anatomy, cardiovascular anatomy, special senses, and cranial nerves. Visual lectures also provided students with a basic understanding of how to 'read' and create anatomical images, focusing on the choices that are made in creating an image, and images as a medium of communication. The visual lectures were provided by the author as a guest lecturer in a course typically taught by another instructor. For more details on the background of visual literacy principles employed, see the literature review on visual literacy (Chapter 2).

	Visual (experimental) A215 lecture	Traditional (control) A215 lecture
Early-semester survey/MRT	123	137
Late-semester survey/MRT	63	57

Table 7.2- a list of the number of participants in each of the surveys used

Students in both populations (visual lecture and traditional lecture) were given a survey (same as in Project 3) and a mental rotation test (MRT) at the beginning and end of the semester, following the same IRB protocol as in earlier projects. Data were de-identified, collected in a database (EXCEL, Microsoft 2010), and paired with anonymous course grades. Both sections were analyzed using SPSS 21.0 (IBM 2012). A correlation matrix was produced as before to explore the grouping of variables in student performance. Latent variables concerning student active-learning and visual-learning approaches were created. T-tests comparing the traditional lecture and visual lecture sections final scores were run.

Having established a baseline of undergraduate study methods for anatomy in the previous phases of this project, a pedagogical intervention was designed to teach students how to use more effective study methods. Knowing that active learning approaches (including visual learning and drawing) typically correlate with better course performance (Drapkin et al. 2015, Freeman et al. 2014, Pickering 2014, Prince 2004, Sweeney et al. 2014), a plan of teaching students to draw anatomical structures was initiated. Additionally, both section of the course were provided with a mental rotation test at the beginning and end of the semester, to examine changes in mental rotation ability based on the method of instruction provided.

Results

Mental rotation scores increased in both the experimental and control groups. The increase in MRT scores in the control groups reconfirms the passive acquisition of spatial ability simply through taking an anatomy course, as seen in Chapter 6 and in other sources (e.g., Vorstenbosch et al. 2013). The experimental group showed a larger increase in MRT, but the change was not statistically significant (Figure 7.1). The control group increased an average of 0.7 points on the MRT (paired t-test p=.34), while the experimental group increased and average of 0.9 points (paired t-test p=0.52). The experimental group started the course with an average of 0.6 points better MRT scores (unpaired t-test p=.36). At the end of the semester the experimental group had an average of 0.5 points higher MRT scores (unpaired t-test p=0.50).

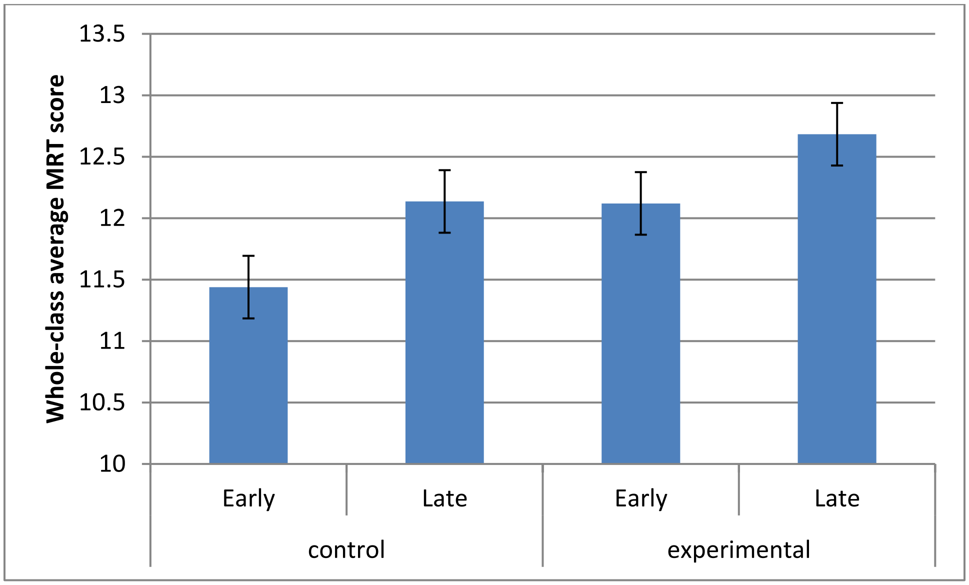


Figure 7.1- Whole-class averages of mental rotation score compared at early- and late-semester times for the control and experimental (using in-class drawing) Anatomy A215 populations.

Visual preference scores (latent variable derived from VARK-style questions on the survey) increased slightly in both groups. Again, the experimental group showed a larger increase than the control, but these changes did not reach $p<0.05$. The control group in this experiment echoes the results in chapter 5, which showed an increase in visual preference without any specific intervention. The early semester preference scores between the two groups were not significantly different($p=0.63$), nor were the late semester scores ($p=0.11$). The control group increase in visual preference score was also not statistically significant (p=0.84). The experimental group increase from early to late semester was also not significant (p=0.08), but it was the largest difference observed.

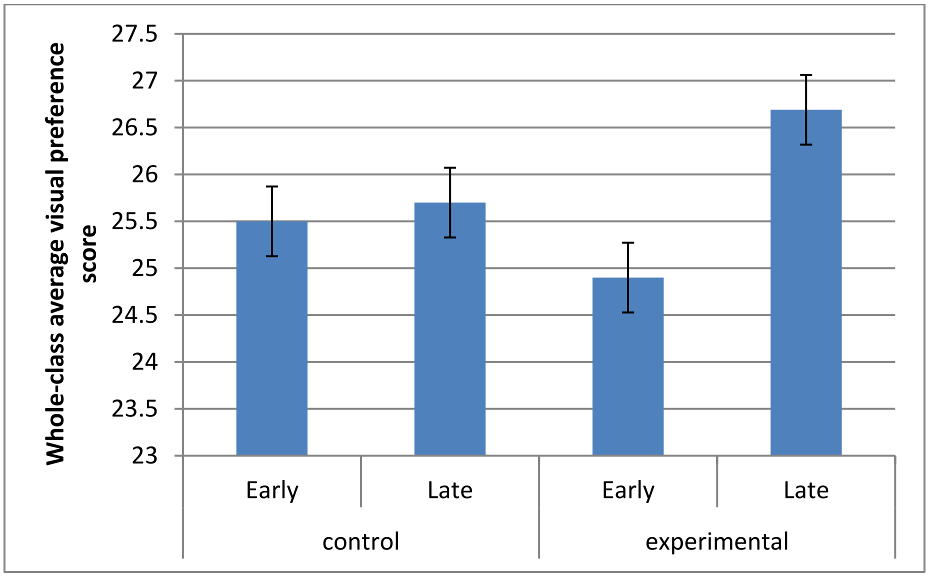


Figure 7.2- Whole-class average of visual preference score at early- and late-semester time points, compared between the experimental and control classrooms. The experimental group demonstrated the greatest gains in visual preference score (for studying).

Visual learning techniques used by students in both groups included re-viewing images, making tables, and making drawings. As seen in chapter 5, the use of these techniques tended to decrease through the semester and within the control group of this experiment. However, usage of visual studying increased in the experimental group (Figure 7.3).

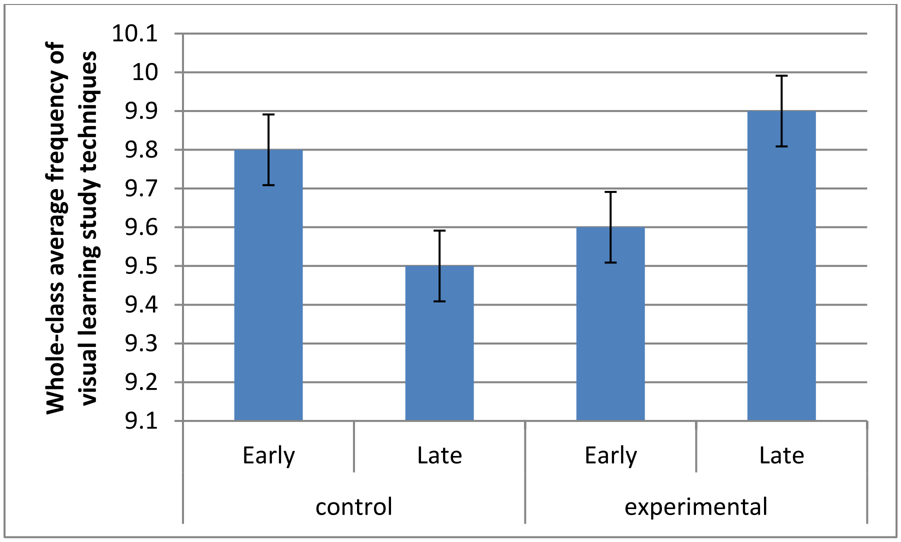


Figure 7.3- Whole-class average of visual study technique usage at early- and late-semester time points, compared between the control and experimental Anatomy A215 classrooms. Visual learning decreased in the control (p=0.34), but increased in the experimental (p=0.36)

In the experimental group, the late-semester survey also asked students to accurately rate their participation in drawing lessons. The participation variable was then correlated with course grade. While the scatterplot (Figure 7.4) shows a completely flat trend line, the data points seem to be clustered into high- and low-participation groups among the top grade earners in the class. These results indicate course success may be helped by drawing, but it is by no means the only way to succeed.

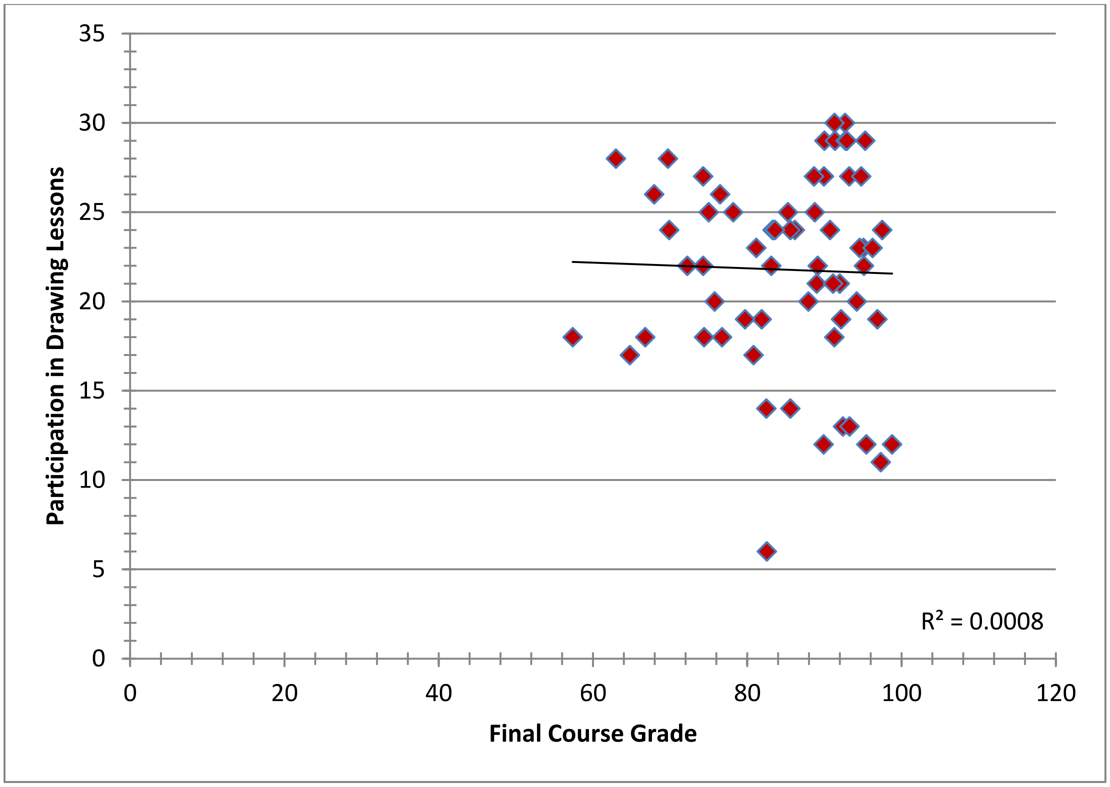


Figure 7.4- Correlation of participation in drawing lessons with final grade (p=0.92). No correlation was seen between participation in drawing lessons and final grade.

Discussion

The drawing intervention discussed in this chapter showed mixed results. Slight improvements in mental rotation scores in the drawing group indicate that instruction in visual literacy may improve spatial ability, but not significantly more than the passive acquisition seen in the control group (Figure 7.1).

Teaching visual literacy also did not significantly change the preferences students had for visual or non-visual learning. However, the slight increase in visual preference should be noted. More importantly, the drawing lessons did seem to change the way students studied. Figure 7.3 shows that use of visual studying increased in the experimental group, but decreased in the control group (and this decrease in visual studying was also seen in Chapter 5).The use of drawing lessons may help to counteract the drop off of visual studying seen in the control group, and help students maintain the motivation needed to continue using active learning as the semester progresses (Robbins et al. 2004).

These results suggest that teaching visual literacy through drawing may help students use more visual approaches in their studying, a factor that has previously been correlated with higher grade in STEM (Ainsworth et al. 2011, Dempsey and Betz 2001, Heuschele 1999, Lyon et al. 2013). Explanations for the drop-off of visual approaches in the late semester group may also include non-cognitive variables, namely motivation (Robbins et al. 2004). Motivation has been shown to be strongly correlated with college success and retention, and typically students using the most active learning (such as making drawings) are the most motivated (Aleven and Koedinger 2000). It is possible that the drawing lessons helped to change some of the non-cognitive influences in students studying, perhaps increasing motivation by demonstrating a novel approach to studying. Active learning has been shown to be strongly correlated with course grades, and is almost certainly better than traditional lecture at helping students gain higher-order thinking skills, and mastery of core concepts (Freeman et al. 2014). If teaching students how to draw does lead to an increase in active learning, as suggested by the results in chapter 7, then it is a technique that should be used more frequently in anatomy courses. Students can use active learning approaches without being taught how to, but explicitly teaching active learning strategies as part of the course should help all students improve their content mastery (Freeman et al. 2014).

CHAPTER 8: Online Drawing Instruction

Student produced drawings have been demonstrated to be an effective tool for learning spatial ability, visual literacy, and course content in science (Ainsworth et al. 2011, Dempsey and Betz 2001, Heuschele 1999, Lyon et al. 2013). Web-based animations have also shown gains visual skills and course content (Ruiz et al. 2009, Evans 2011). "Draw along tutorials" are the combination of these two features, and have only rarely been examined in the literature (Evans 2011, Pickering 2014).

The research facet detailed in this chapter examines the use of an on-line series of video tutorials designed to teach students neuroanatomy content (Draw It to Know It 2016). This research was guided by the following questions:

Research Question 8: Does the use of an online software tool for anatomy drawing change student mental rotation scores, or their attitudes and use of visual learning study skills?

The previous question (#7 found in Chapter 7) investigates the use of in-class drawing as a pedagogical intervention to teach visual literacy and mental rotation skills to students. This question (#8) investigates whether drawing lessons can be effective if delivered through web-based video tutorials.

Methodology

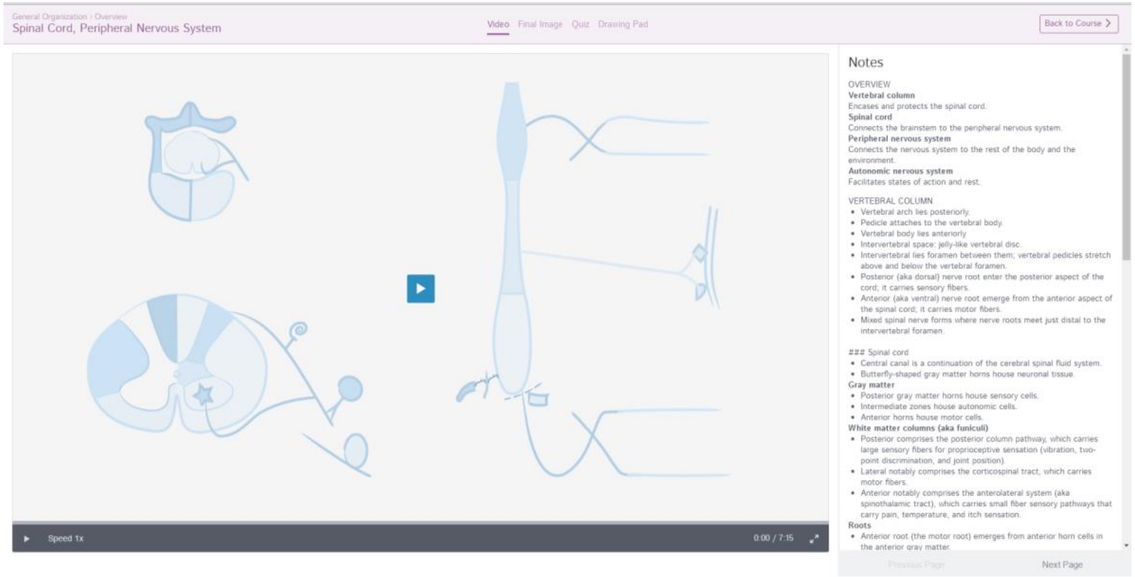
Project 5 “Web-based drawing instruction” 2014

Project 5 was designed to answer research question 8, “can a web-based tool be used to teach visual studying or mental rotation?” Web-based “draw along” videos (also called screencasts) have shown some success in teaching anatomy content in other publication (Pickering 2014, Evans 2011).

This project used a slightly different form of the earlier survey (see appendix A), as it had to be re-written for deployment online, and had a different student population. The survey consisted of 16 questions about the frequency of use of a variety of study skills, 7 questions about the students’ self-perception as a visual learner, and 5 questions about their opinions of the software.

The mental rotation test (MRT) was originally designed by Bodner and Guay (1997) for use with chemistry students, but use of mental rotation tests is well-established as a proxy for spatial ability in the educational literature (Chatterjee et al. 2011, Lufler et al. 2012, Meneghetti 2016). The MRT contains 20 questions which ask the participant to mentally manipulate a 2-dimensional drawing of a 3-dimensional, geometric object. Each question consists of an example rotation of one object which the participant must then reproduce in a new object, via analogy, and choose the correct answer from a multiple-choice list of four options. The final score on the test is calculated out of twenty points, based on the number of correct answers. The test is timed with ten minutes being allotted for completion. Incomplete items are scored as incorrect.

The web-based software tool used was *Draw It to Know It* (Draw It to Know It 2016). This software was originally designed as a review tool for neurology residents, but was substantially re-written to work with neuroanatomy and neuroscience content at all levels. The aim of the software is to present neuroanatomy concept in a series of short (3-8 minute) video tutorials, in which the student draws anatomical structures along with a narrator demonstrating the drawing. The tutorials also include information about the functional aspects of the anatomy being described.



Notes

OVERVIEW
Vertebral column
Encases and protects the spinal cord.
Spinal cord
Connects the brainstem to the peripheral nervous system.
Peripheral nervous system
Connects the nervous system to the rest of the body and the environment.
Autonomic nervous system
Facilitates states of action and rest.

VERTEBRAL COLUMN
- Vertebral arch lies posteriorly.
- Pedicle attaches to the vertebral body.
- Vertebral body lies anteriorly
- Intervertebral space: jelly-like vertebral disc.
- Intervertebral lies foramen between them; vertebral pedicles stretch above and below the vertebral foramen.
- Posterior (aka dorsal) nerve root enter the posterior aspect of the cord; it carries sensory fibers.
- Anterior (aka ventral) nerve root emerge from the anterior aspect of the spinal cord; it carries motor fibers.
- Mixed spinal nerve forms where nerve roots meet just distal to the intervertebral foramen.

Spinal cord
- Central canal is a continuation of the cerebral spinal fluid system.
- Butterfly-shaped gray matter horns house neuronal tissue.

Gray matter
- Posterior gray matter horns house sensory cells.
- Intermediate zones house autonomic cells.
- Anterior horns house motor cells.

White matter columns (aka funiculi)
- Posterior comprises the posterior column pathway, which carries large sensory fibers for proprioceptive sensation (vibration, two-point discrimination, and joint position).
- Lateral notably comprises the corticospinal tract, which carries motor fibers.
- Anterior notably comprises the anterolateral system (aka spinothalamic tract), which carries small fiber sensory pathways that carry pain, temperature, and itch sensation.

Roots
- Anterior root (the motor root) emerges from anterior horn cells in the anterior gray matter.

Figure 8.1- an image from the Draw It to Know It software. The drawing tutorial panel is visible on the left of the image, with the right pane of the image showing the terms and concepts to be learned in this tutorial.

This software had not previously been evaluated as to its educational effectiveness, so Project 5 was designed to assess the software using the surveys and mental rotation tests (MRT) as used in the previous educational research projects described in earlier chapter (chapter 4-7 above).

The sample population for this project (n=97) came from a total population of undergraduate and professional students (n=1352) in nearly 40 different neuroanatomy and neuroscience courses from across the United States.

These students were enrolled in a variety of courses at all educational levels, including undergraduates, medical students, physical therapy students, and osteopathic medicine students. Surveys and MRTs were deployed through the *DITKI* website, and a Study Information Sheet (previously called Informed Consent Statement) allowed students top opt-in to the data-collection portion of the project. Those students who opted in completed a survey at the beginning of their neuroanatomy course, and another at the end. They were also asked to complete the MRT at the same two time points.

De-identified student data were collected in a database (Excel Microsoft 2010) as before, and analyzed using SPSS 21.0 (IBM 2012). A notable difference in this data analysis is the lack of student final grades. Due the constraints of ethical research across multiple campuses, no course performance metrics were collected, and the data analysis relies on student self-reported satisfaction with the software, and their perceived quality of learning from it.

Only 97 students completed all surveys and tests. These 97 students are the only ones assessed in the following results. Due to software limitations, partial data were not available, and only those student completing all surveys and MRT tests were included in the data analysis.

Results

All students in the survey reported high satisfaction with the software, finding it both useful and effective. Because course performance metrics were not available, student survey responses could not be compared on final grades. Students were instead compared based on their measures of visual learning strategies, and use of active learning strategies. Students who reported frequent use of active learning strategies found the software to be significantly better (useful and efficient) than their peers who used more passive learning strategies (Figure 8.2).

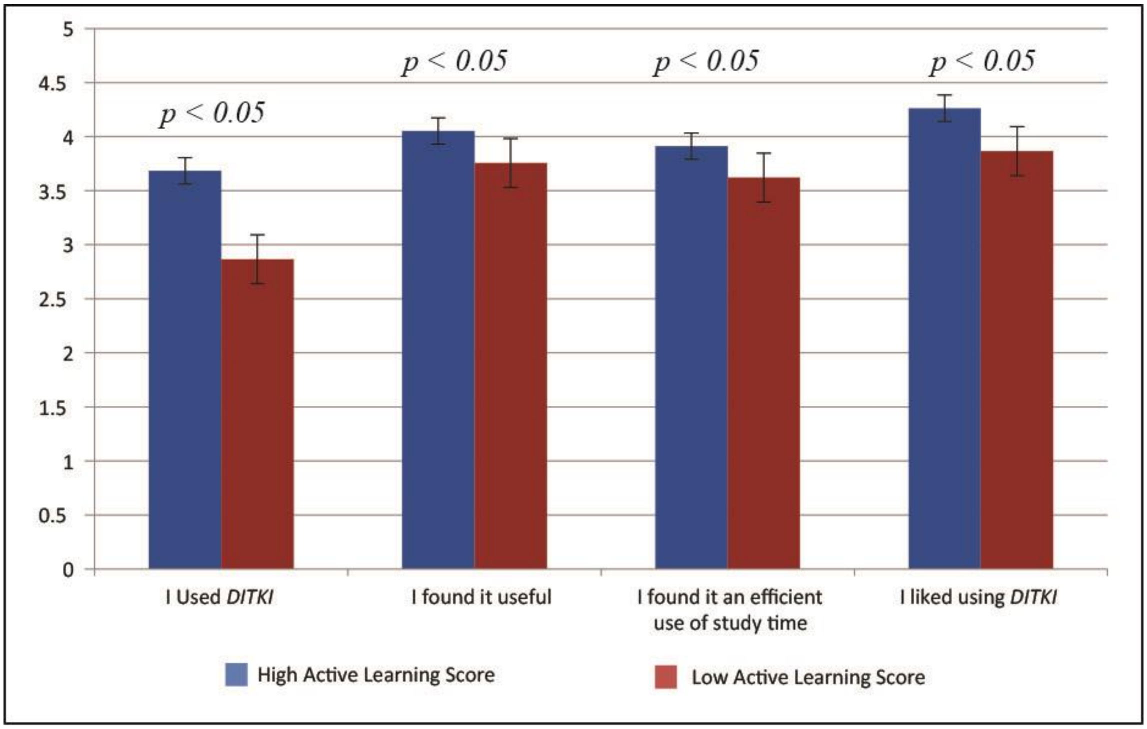


Figure 8.2- Comparisons of mean values on a 5-point Likert scale for the usefulness and efficiency of the software. The two groups were divided by their use of visual learning approaches based on survey responses.

Students who reported frequent use of visual learning strategies in their study time found the software more efficient and enjoyable than students who rarely used visual learning skills (Figure 8.3). Interestingly, the frequent and infrequent visual studiers did not differ significantly in their perceived usefulness of the software.

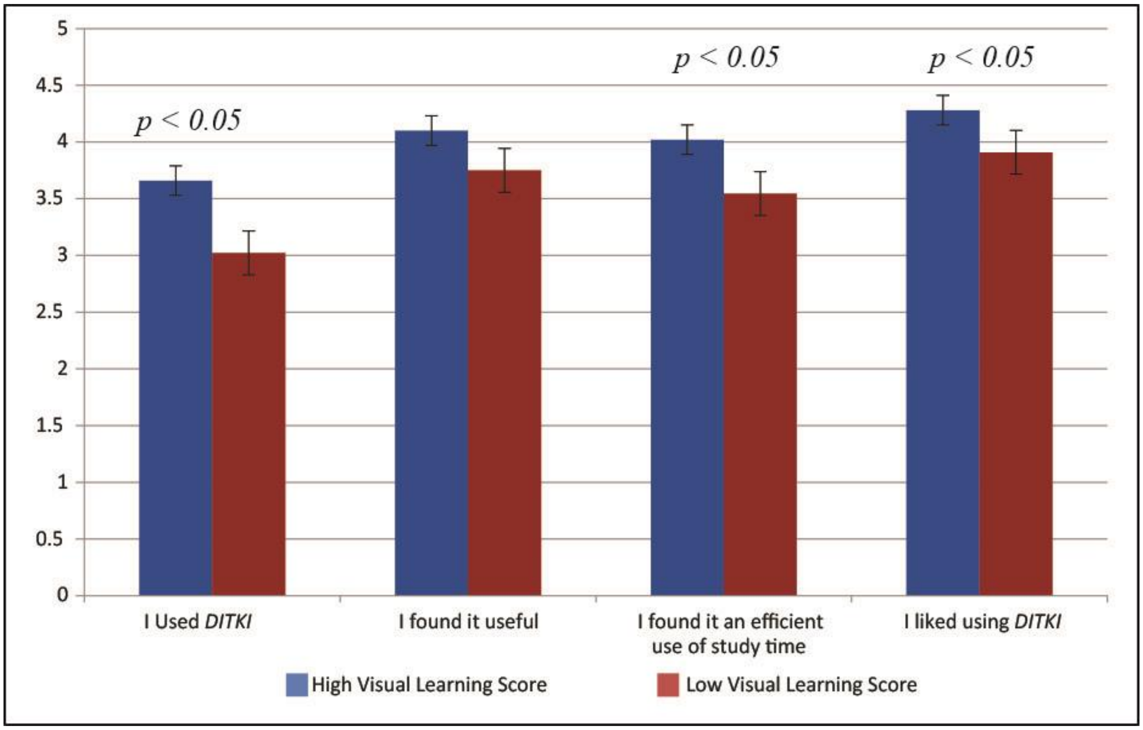


Figure 8.3- Comparisons of mean values on a 5-point Likert scale for the usefulness and efficiency of the software. The two groups are divided by their use of active learning approaches based on survey responses.

Discussion

There have been limited publications discussing the use of computer software to teach anatomy through drawing (Evans 2011, Pickering 2014). The results that have been published indicate that students typically like the ability to practice at their own pace, and enjoy the flexibility of web-based narrated anatomy lessons. However, there are no reports of actual effectiveness of these tools. Other fields have used similar software tools, and all report great enthusiasm by the students (Green et al. 2012). While the students have received these programs with enthusiasm, no positive effects on learning have been demonstrated, but they have also not been shown to be detrimental (Green et al. 2012). The research presented here falls into the same category; enthusiastic support from students, but no measurable outcomes on learning.

Despite the lack of measurable learning goals, the uniform enthusiasm from all groups of students (high to low visual study skill users, and high to low active learning users) indicates that learning style preference does not dictate the perceived effectiveness of different instructional methods. Students who do not necessarily like using visual approaches in their studying report that drawing was a valuable way to study, even if they do not like it. This indicates that drawing and visual literacy can be taught to all students, even if they are do not consider themselves visual learners. Learning styles (or preferences) have long been debated (Davidson and Richie 2016, Fleming and Baume 2006, Fleming et al. 2006, Ganesh 2014, Gradl-Dietsch et al. 2016, Hawk and Shah 2007, Leite et al. 2010, Lujan et al. 2006 Yazici 2016). These results indicate that students who claim to have a dislike for visual learning still appreciated being taught in a visual way. It may be that learning preferences are more related to the course content than a fundamental preference in the individual (Farkas et al. 2015, Leite et al. 2010, Riener and Willingham 2010). Even students who consider themselves to be non-visual learners should be encouraged to try visual approaches to studying, as indicated by the results in this dissertation. Students should also be warned about the potential pitfalls of holding too strongly to a learning preference, given the controversy present in the learning styles literature.

The following chapter will revisit all of the above research projects and recapitulate the thematic connections between the various research facets. A global discussion tying all of the results together is included. Limitations and future directions will be discussed.

CHAPTER 9: Conclusions

Each previous chapter contained a brief discussion of the relevant results, and explanation of how each ties into the overall project. This chapter will re-examine the most pertinent results from previous chapters, and draw connections between all of the disparate projects to further explain the thematic connections running throughout this dissertation. The first section will restate the main research questions that formed this dissertation. The second section will re-address each individual study facet and how it connects to the research questions. The third section will discuss the results of each research facet and how those results relate to the original research questions. The fourth section of this chapter will discuss limitations of each project, and outline future directions for research to address each limitation.

The research presented in this document is comprised of a series of smaller projects (also called 'facets') all designed to explore a number of larger research questions (see Table 9.1).

Facet	Populations Examined (Chapter 3)	Main Research Question (Chapter 3)	Subordinate Research questions	Chapter
1. Study Skills Survey	A215 P215 A550 P531	What study methods do students use?		4
2. Visual study skills	A215	Do students use visual study methods?	Does the use of visual studying change during the course?	5
3. Mental Rotation	A215	How much spatial ability do students have?	Does spatial ability change during the course?	6
4. In-Class Drawing	A215	Does the use of in-class drawing lessons improve SA or VL?		7
5. Web-based video tutorials	Various	Does the use of web-based drawing tutorials improve SA or VL?		8

Table 9.1- The relationship between research questions and the individual facets of the larger research plan.

An outline of the research questions used in this research are listed below:

1. How do students study for anatomy?
2. How frequently do students use each study technique?
    a. Do medical students and undergraduates employ different study strategies?
    b. Do medical students and undergraduates spend different amounts of time with each specific study habit?
    c. Do students use different study habits in anatomy courses as compared to physiology courses?

3. Do different study habits lead to different course outcomes, when controlled for student demographics?
4. How often do anatomy students use visual study skills?
5. Are there differences in student self-reported visual learning measures?
    a. Do students who self-report a preference for visual learning use visual study skills more often?
    b. Do students who self-report a preference for visual learning do better in course performance metrics?
6. Do student study habits change during the semester?
7. Do undergraduates enter an introductory anatomy course with adequate mental rotation scores?
    a. Do mental rotation scores change during the semester?
    b. Do mental rotation scores change, given specific instruction in anatomical drawing?
    c. Do mental rotation scores correlate with course performance metrics?
8. Does the use of an online software tool for drawing change student mental rotation scores, or attitudes and use of visual learning?

Discussion

The research questions in this dissertation are each addressed by one or more facets. The first set of research questions examines study skills and was addressed by facet 1 in the table above. The results of facet 1 “Study skills survey” will be discussed following a restatement of the research questions.

Research Question 1: What methods do students use to study for anatomy or physiology?

The students in this question are considered broadly and come from populations in A215 (anatomy undergraduates), A550 (first-year medical anatomy), P215(physiology undergraduates) and P531(first-year medical physiology) as described in chapter 3. Instructors in all listed courses provide students with numerous tips and tools for efficient study, but it is unclear which of those techniques the students use. Study tips provided in all classes include active learning techniques and student-produced drawings (as seen in the syllabus excerpts, Appendix C). Educational research literature indicates that use of the above study techniques is effective, but it is unclear whether there is a correlation between use of the suggested study techniques and final grades in the courses studied (Barger 2012, Husmann et al. 2016, Vasan et al. 2009, Zumwalt et al. 2010). This first question was designed to look at the study techniques students report actually using, and how student use of study techniques compares to the recommendations provided by instructors.

Research Question 2: **How frequently do students use each study technique for the learning of anatomy?**

More specifically, this research question may be subdivided into the following questions:

d. **Do medical students and undergraduates employ different study strategies?**

e. **Do medical students and undergraduates spend different amounts of time with each specific study habit?**
f. **Do students use different study habits in anatomy courses as compared to physiology courses?**

This second research question is closely related to the first, and serves to elucidate some of the other ideas contained in the question of "what methods do students use to study anatomy?" This second question was designed to look more closely at differences in student populations, and if successful study strategies are transferable to new contexts. The students indicated in this question come from four courses: A215 (anatomy undergraduates), A550 (first-year medical anatomy), P215 (physiology undergraduates) and P531(first-year medical physiology).

Research Question 3: Do different study habits lead to different course outcomes, when controlled for student demographics?

Knowing what activities students are doing in their study time is only the first step in helping them to use that time more effectively. The next obvious step is to discover which strategies, if any, correlate with course outcomes. Again, the educational research literature (Barger 2012, Husmann et al. 2016, Mitchell et al. 2004, Vasan et al. 2009, Zumwalt et al. 2011) is full of details concerning effective study strategies, but it was unclear how these broad principles apply to the populations considered here.

Student study habits- Question 1-3, Facet 1, Chapter 4

Results of the research in this dissertation indicate that there is no ‘best’ way to study. That is, there were no significant correlations between study habits and final grade in any of the sampled populations. All of these populations demonstrated a wide variety of study skills, with varying degrees of success. Among the top scoring students in all courses, there were no single study techniques used most frequently. However, a slight positive correlation with all active learning techniques and final course grade was observed. A negative correlation between use of passive learning techniques and grade was also observed. Regardless of course or student educational level, there is weak support for active learning as an effective method of studying anatomy and physiology. The most frequently used study techniques tended to be passive, with reading the text and reviewing course notes as the most frequently used. The lack of active learning may relate to motivation (Karpicke et al. 2009, Phinney et al. 2005), strategic learning (Biggs 2001), or assessment style (Hart 1994, Gurung and McCann 2011, Schwartz and Gurung 2012, Wiggins 1990). Medical students and undergraduates did not use dramatically different study methods, but anatomy students and physiology students did show some differences in the use frequency of some study techniques. Both of these findings (little difference in studying based on educational level, but large differences between courses) are supported by other published research (Gurung and Schwartz 2009, Husmann et al. 2016).

The next set of research questions address the study facet 2 “visual learning in anatomy.” The research questions are restated, followed by a discussion of the results of facet 2.

Research Question 4: How often do anatomy students use visual study skills?

This question is the central idea guiding the overall research plan. The preceding research questions (research questions 1-3) were investigated as background information about basic study habits before visual study habits could be addressed. It was worth investigating the basic study habits of students to create a framework of potential study methods before focusing too closely on only one specific subset of study skills. Having collected the data from the projects guided by research questions 1-3, it became clear that students use a wide variety of study habits, and there are some potential differences in course outcomes based on how a student chooses to study. Knowing that study strategies matter, and having read some of the publications concerned with the debates (e.g., what kind of images are ‘best’?, are spatial ability and visual literacy really different?) in visual learning (see chapter 2 for references), it was decided that a focus on visual learning (visual study skills) was a valuable next question.

The literature review and introduction chapters (see previous section this chapter) are full of justifications and research explaining the utility of visual learning (especially mental rotation and spatial ability) in a variety of fields, including other sciences, as well as anatomy, but the use of visual study skills in novice students has not been fully explored in the existing literature (to clarify, mental rotation and spatial ability are well explored in the existing literature, but the use of visual study skills, as defined in Chapter 1 of this dissertation, is not widely reported).

Research Question 5: Are there differences in student self-reported visual learning measures?

More specifically:

a. Do students who self-report a preference for visual learning use visual study skills more often in their anatomy courses?

b. Do students who self-report a preference for visual learning do better in anatomy course performance metrics?

This question was designed to look at differences in student perceptions and uses of visual learning in anatomy. Students enter anatomy courses with a wide variety of previous experiences, and it is unclear how those experiences shape a student's study habits. This question asks whether different students use different study habits without any intervention from the instructors or researchers.

Visual Literacy- Question 4-5, Facet 2, Chapter 5

Visual literacy has been notoriously hard to study and evaluate (Avgerinou and Ericson 1997, Perkins 1994, Wiles 2014) but the research in this facet of the dissertation attempted to measure visual literacy through survey questions about the students' use of visual study habits and their preferences for visual methods of study. Students in this study were anatomy undergraduates in the A215 course.

The use of visual study techniques among these undergraduate students was highly variable, and not correlated with course grades. Some undergraduates succeeded in anatomy with frequent use of visual study techniques, while others rarely used visual skills and achieved the same grades. Interestingly, a student's self-reported preferences for visual learning did not correlate with his/her preferred study methods in anatomy. That is, students who claimed to be visual learners did not necessarily use more visual learning skills in their anatomy study time (see also for discussion of learning style and study skills Farkas et al. 2015, Leite et al. 2010, Riener and Willingham 2010). This result may be related to the method of testing used in the undergraduate anatomy course. The lecture exams in this course do not emphasize visual understanding, so the lack of visual studying may represent a strategic approach by the students (Biggs 2001). Additionally, the pervasive belief that anatomy is 'all memorization' may lead students to use less effective strategies, or to revert to old habits that were successful in memorizing content for earlier courses. The lack of statistically significant correlations between preference and actual study habits points back to the historic debates in this field, and indicate the need for further study in the ways students learn how to use visual images in science (see Chapter 2 references on this subject). It may be that an indicated preference for visual learning is actually unrelated to visual literacy, and the surveys attempting to measure visual literacy were based on faulty assumptions about student preferences. The literature on learning styles and student preferences is an active source of debate (Davidson and Richie 2016, Fleming and Baume 2006, Fleming et al. 2006, Ganesh 2014, Gradl-Dietsch et al. 2016, Hawk and Shah 2007, Leite et al. 2010, Lujan et al. 2006 Yazici 2016). Future research may be to elucidate the connections between visual preferences and visual literacy.

The following section introduces a time component to the surveys used in an attempt to capture the changes in student study habits and preferences during the semester. The previous study facets only considered students at the end of their anatomy (or physiology) courses, but understanding the changes in study habits that occur during an anatomy course is poorly understood.

Research Question 6: Do student study habits for anatomy change during the semester?

All of the previous questions rely on sampling students at a single time point in the semester. Question 6 allows for the exploration of study habit changes in students during a course, including those habits related to visual learning and spatial ability. It has been suggested in some visual literacy literature (e.g., Orion et al. 1997, Titus and Horsman 2009, Vorstenbosch et al. 2013) that simply taking a science course can lead students to changes their habits and increase their visual literacy and spatial ability. As students navigate the challenges of a course, and experiment with new ways of learning, they may change their study habits, without any specific suggestions from instructors. More frequently, the published literature in anatomy education deals with specific pedagogical interventions designed to help students in one specific aspect of the course. There have been many interventions related to spatial ability and visual literacy published (e.g., Allen et al. 2014, Azer and Azer 2016, Bareither et al. 2013, Faurie and Khadra 2012, Garg et al. 2001, Gradl-diestch et al. 2016, Keehner 2011, Keehner et al. 2008, Khot et al. 2013, Kotze and Mole 2015, Knobe et al. 2013, Kooloos et al. 2014, Moscova et al. 2014, Murphy et al. 2014, Ngan et al. 2010, Ngan et al. 2012, Nguyen et al. 2014, Nguyen et al. 2011, Nguyen et al. 2009, Noel 2013, Preece et al. 2013, Richardson-Hatcher et al. 2014, Ruisoto et al. 2012, Ruiz et al. 2006, Ruiz et al., 2009, Saltarelli et al. 2014, Schwibbe et al. 2016, Smith 2015, Smith et al. 2015, Sweetman et al. 2013, Tam 2010, Topping 2014, Trelease and Nieder 2013, Vorstenbosch et al. 2013, Weber et al. 2016, Willis and Martin 2016, Yammine and Violato 2014). For a full list, and details on the various methods that have been tried, see chapter 2. The problem with the intervention literature is that it rarely captures the changes that happen to students simply from taking a course. This question was designed to capture the changes in student study habits that happen without intervention, to establish a quasi-control for the following questions, all of which deal with specific interventions.

Changing study habits- Facets 2-3, Chapter 5-6

The question of changing study habits was addressed by research facets 2 and 3, and can be found in chapters 5 and 6. It was found that study habits do change during the semester, often by becoming more passive and less visual. In the absence of instructor intervention (by emphasizing active or visual learning techniques, as seen in chapter 7) students will tend to study less, and study less actively as the course progresses. These changes may be related to non-cognitive factors outside the scope of the surveys used. However, focusing only on the cognitive determinants of course performance (i.e. study skills) shows that active learning tends to be correlated with course grade, but even the top scoring students tend to become more passive during the course. Having found that study skills tend to drop off during a course, the interventions found at the end of this chapter sought to improve study habits, and improve course grades.

Research Question 7: Do undergraduates enter an introductory anatomy course with adequate mental rotation skills (MRT scores)? More specifically:

a. **Do mental rotation (MRT) scores change during the semester?**
b. **Do mental rotation scores change, given specific instruction in anatomical drawing?**
c. **Do mental rotation scores correlate with anatomy course performance metrics?**

Previously published literature suggests mental rotation abilities (summarized in the spatial ability section of Chapter 2) of novice students can be highly variable (Vorstenbosch et al. 2013, Ruisoto et al. 2012, Ruiz et al., 2009, Faurie and Khadra 2012, Keehner 2011, Keehner et al. 2008, Garg et al. 2001). In general, students rarely have enough experience with mental rotation (or similar spatial ability tasks) to have good MRT scores, which can make learning anatomical relationships more challenging (Keehner et al. 2006, Provo et al. 2002, Lufler et al. 2012, Luursema et al. 2008, Boudreau et al. 2008, Hegarty et al. 2009, Wanzel et al. 2002, Fuks et al. 2009, Garg et al. 2001). While there is a long-standing misconception among students that the study of anatomy is equivalent to memorizing a long list of names, a large part of the study of anatomy is understanding the relationships of anatomical entities in the human body. To understand structural relationships, one must know the three-dimensional shapes and locations of anatomical structures. Understanding three-dimensional shapes is not an easy task; it requires practice to learn how complex 3D objects interact in the body. A high spatial ability (or mental rotation ability) may make this task easier. It is the goal of research question 7 to see how spatial ability relates to anatomy performance and study skills.

Mental Rotation: Question 7a, 7c., Facet 3, Chapter 6

Spatial ability was measured by a mental rotation test (MRT). The MRT was created and validated by Bodner and Guay (1997), and mental rotation is an acceptable proxy for spatial ability as a whole (Meneghetti et al. 2011, Meneghetti et al. 2016, Uttal et al. 2013). In research facet 3, mental rotation scores did not correlate with course performance, or with any of the study skills assessed by the survey. Surveyed populations included undergraduates in anatomy (A215). However, the MRT scores did increase slightly during the semester, even without specific instruction in spatial ability, an indication of the reciprocal relationship of anatomy and spatial ability as seen in Vorstenbosch et al. (2013). It has been proposed that studying anatomy acts as a way of practicing spatial ability, even when it is not given that name. Students (especially undergraduates who may not go on to use anatomy professionally) should be reminded of the practical implications of studying anatomy in terms of learning spatial ability. That is, understanding the relationships of 3D structures in the body may have benefits beyond ‘memorizing terms.’

Research Question 8: Does the use of an online software tool for anatomy drawing change student mental rotation scores, or their attitudes and use of visual learning study skills?

The previous question (7b) investigates the use of in-class drawing as a pedagogical intervention to teach visual literacy and mental rotation skills to students. This question (8) investigates whether drawing lessons can be effective if delivered through web-based video tutorials.

Pedagogical interventions: In-class drawing tutorials and web-based video drawing tutorials. Questions 7b-8, Facets 4-5, Chapters 7-8

The two facets discussed in this section were reported separately in chapters 7-8, but will be discussed together because they both deal with attempts at teaching visual literacy and spatial ability to anatomy students. Populations sampled to answer this question came from the undergraduate anatomy course A215.

Students are often encouraged to create their own drawings as a way of understanding anatomy content (see appendix C for course syllabuses). However, students are rarely given enough instruction in creating images to use this study technique effectively. The surveys used in Chapters 4-5 asked students to rate how frequently they produced their own drawings while studying. Students reported frequent use of this technique in their studying, but it is unclear if this technique is actually effective, as it did not correlate with course grades. In an effort to make student-produced drawings more effective, facets 4-5 of this dissertation taught students some of the basics of drawing for communicating science (Ainsworth 2011).

Facet 4 used in-class drawings to communicate anatomy content to students and provide them with the tools needed to make their own drawings outside of class time. Students who participated in these drawing lessons reported that drawing is a useful way to learn content, but rarely transferred this study method to new contexts. That is, even among students who participated in the drawings, enjoyed drawing, and showed a high preference for visual studying, they rarely made their own drawings for studying. The drawing participants also did not show any significant improvement in course grades, or mental rotation scores, as compared to students taught through traditional didactic lectures. Drawing as a tool for learning is highly regarded in the educational literature (Ainsworth et al. 2011, Dempsey and Betz 2001, Heuschele 1999, Lyon et al. 2013) but empirical evidence for its usefulness in conveying course content is mixed (Van Meter and Garner 2005). The evidence for drawing also indicates that drawing can lead to cognitive improvements outside of a discipline-specific domain (Lyon et al. 2013). Visual literacy is important to understanding science, and the drawing lessons provided in facet 4 may have improved visual literacy, even if anatomy content delivery was unaltered.

Facet 5 used a web-based drawing tutorial video series (*Draw It to Know It*) to teach drawing outside of class time. One of the limitations of Facet 4 was the limited number of drawing lessons that could be provided to students. By moving the drawing content online, the number of drawing lessons a students could potentially experience was greatly increased. The online format provided the additional benefit of repeated practice, pausing and rewinding, and a lower stress environment than a classroom. Students reported liking all of these features of the drawing tutorials, and all students found the tutorials a useful and efficient way to study. Regardless of self-reported preferences for different types of studying, all participants in the *Draw It to Know It* study reported a high degree of satisfaction with it as a way of learning anatomy content. Unfortunately, the logistical limitation of working with multiple study sites prevented the collection of certain data. IRB restrictions prevented the collection of course grades, and recruitment at different campuses was not monitored, leading to the potential loss of some study participants.

The final research question is addressed below. It is not a specific, measurable question, but a reminder of the underlying interests that began this dissertation research.

Research Question 9: What are the best ways to study anatomy, and is visual learning an important part of the student experience? What are the pedagogical implications of the research questions 1-8? That is, what should instructors do to ensure students are getting the most benefit from an anatomy course?

Question 9 is less of a research question than it is a guiding principle, a reminder of the overarching goals, and an opportunity to tie all the above research questions together. All of the preceding questions were treated as largely separate to make each individual project as specific as possible, but all of the questions work together to address to problem of student learning in anatomy, which is the ultimate goal of the entire series of research projects. Question 9 is almost impossible to answer in isolation, but it is the ultimate goal of this dissertation to address this problem, and provide answers to the question of "what is the best way to study?" As has been seen in the research literature cited throughout this dissertation, there is no 'best way to study.' In fact, defining 'best' in this context is impossible. Does "best" mean getting the highest course grade? Does best mean having the most long-term retention? Does best mean improving multiple cognitive facets while learning discipline specific material? Does best have a non-cognitive component? In trying to define useful approaches to studying, the shifting definitions of 'best' must be kept in mind.

The hypotheses implicit in the research questions were that improving visual learning and spatial ability skills would lead to better course performance in anatomy students. While SA (and to a lesser extent VL) have demonstrated correlations with anatomy performance (e.g., Boudreau et al. 2008, Hegarty et al. 2008, Lufler et al. 2012), improving anatomy scores through teaching VL and SA has yet to be definitively demonstrated. While teaching VL and SA may not lead to directly improved anatomy scores, it is worth noting how useful these skills are in other areas. For example, visual literacy has been linked to 'critical observation' in clinical reasoning (e.g., Bardes et al. 2001, Boudreau et al. 2008, Bardes et al. 2001). Visual literacy (and visual thinking) have also been described as a method of flexible or deep retrieval, and is a crucial part of becoming an expert in a field of study

(Bransford et al. 2000). Novice students tend to think very algorithmically, and lack the flexible retrieval of experts; training in visual literacy has been shown to help students break their algorithmic thinking patterns (Stieff et al. 2010). If anatomy courses (especially for medical students) are part of a training program to get the novice student to think like an expert, then visual literacy is a crucial part of this goal. Outside of anatomy, basic visual literacy skills are important for any type of visual communication, including advertising (Alenn 1994, Glasgow 1994), understanding science (Ainsworth et al. 2011, Dempsey and Betz 2001, Heuschele 1999, Lyon et al. 2013), and even problem solving (Kozhevnikov et al. 2007).

Spatial ability has been shown to correlate not only with anatomy, but other sciences (Orion et al. 1997), map reading (Lawton 1994), and mathematical reasoning (Linn and Peterson 1986). Improving visual skills has a definite place in anatomy education, even if it does not always lead to higher exam scores. Using student-produced drawings to teach visual skills has demonstrated effectiveness (Ainsworth et al. 2011), but is not without its detractors (Van Meter and Garner 2005 for a meta-analysis of drawing in science). Perhaps the strongest argument for teaching drawing (as a means of visual communication) is the metacognitive component (Lyon et al. 2013). To make an effective drawing, a student must have a firm grasp of the content s/he wishes to draw. To produce an accurate drawing, a student is required to honestly evaluate what s/he knows, thereby increasing metacognitive awareness. Frank Netter, noted medical illustrator and physician put it best when he said:

> “The making of a picture is a stern discipline. One may ‘write around’ a subject where one is not quite sure of the details, but [in an image] one must be precise and realistic. The white paper before the artist demands the truth.” (Netter 1989, back cover)

Limitations

Some limitations exist in this research. Student participation in surveys may not accurately represent the entire class. Because students were not mandated or incentivized to complete surveys, there was a large number of students who did not participate in the research. The non-uniform participation in surveys could lead to a selection bias, in which the sample is not representative of the population (Berk 1983). While survey participant grade distributions and demographics were similar to the class a whole, there may still be a selection bias present.

Additionally, surveys relied on students to accurately self-report their habits and opinions. Self-reporting on surveys is subject to (at least) two different biasing factors: social desirability bias (Furnham 1986) and acquiescence bias (Knowles and Nathan 1997). Social desirability bias can cause participants to over-report perceived good behaviors, and may have caused students to overestimate their study habits. Acquiescence bias is the tendency for survey respondents to agree with all questions on a survey, which could also have led to an overestimation of study habits in this research.

The mental rotation test was given to students at two time points during the semester, which means it is susceptible to the test-retest effect (Windle 1954). This effect indicates that scores will typically improve on a retest due to lower testing anxiety, and a familiarity with the questions, even if the subject has not actually changed. This effect is most prominent in short-interval test-retest situations, typically under two months. In my experimental design, the test-retest interval was close to three months, but an effect may still exist.

Course assessments (e.g., lecture and lab exams) may not have authentically assessed the variables being measured in the research (Wiggins 1990, Hart 1994). Authentic assessment refers to directly testing students on the intellectual tasks they should know. An assessment may be deemed authentic if it directly and accurately measures what has been taught in a course. Simply put, does the exam actually test what the instructor thinks it tests? The assessments used in the anatomy courses surveyed in this dissertation were surely authentic in their anatomy content, but may not have directly assessed VL or SA as authentically as desired. That is, course grades may not have been the best way to measure improvements in anatomy learning through VL and SA. In the courses described here (see above for details in the Methodology Chapter 3), students were assessed with multiple-choice exams, with most questions focusing on identification of written descriptions, meaning visual literacy was not important for success in the course. Laboratory exams were based on identifying static structures, which is a visual skill, but a very low-level visual task, again meaning that visual literacy was not being well assessed. Anatomy taught through didactic lecture and largely passive laboratory sessions does not emphasize the visual aspects under examination in this research. Related to the assessment problem, the teaching methods used in the course did not emphasize the visual understanding of anatomy being tested in the surveys.

Non-cognitive factors (e.g., motivation, peer support, and financial support) have been shown to be important determinants of student success in higher education (Robbins et al. 2004). It is possible there were non-cognitive factors, especially motivational factors underlying some of the unexpected changes seen in student study habits. The surveys did not assess any non-cognitive variables.

Gender differences in spatial ability (mental rotation) were not considered due to sample size limitations and unequal gender distribution in the undergraduate anatomy course. The undergraduate anatomy (A215) typically enrolls 80% female students, creating an skewed environment for investigating gender differences in study habits or mental rotation skills. There is still an active debate about the role of gender in spatial ability (e.g., Hyde 2016, Masters and Sanders 1993, Moe 2016, Quaiser-Pohl 2016, Voyer et al. 1995, Xiong et al. 2016, for a more complete examination of gender in spatial ability, see Chapter 2). If a gender difference in spatial ability does exist in the population as a whole, its causal factors are not yet understood (Quaiser-Pohl 2016).

Sampling bias was of particular note in chapter 8 due to the low participation from the available pool of participants. Over 1300 students were asked to complete the surveys and MRTs for the research on *Draw It to Know It*, but only 97 did. While 97 is a large enough number for statistical reliability, and the participants were a good representative of the total courses enrolled in the survey, there is no way to ensure those 97 participants accurately represent the entire population. I was unable to monitor recruitment on the various campuses where *Draw It to Know It* was provided, so it is unclear how aware of the study the students were. Additionally, ethical research standards prevented incentives from being provided to students completing the surveys, possibly leading to more loss of participants.

Future Directions

The limitations presented above point the way to interesting future directions for this research.

Authentic assessment, non-cognitive factors, and qualitative data are the three most interesting areas for future research. These three factors seemed to be the biggest confounders (or missing variables) in the data. Additionally these three issues may be addressed without the need for larger samples or better student participation in surveys (a logistical nightmare faced by all educational researchers).

Authentic assessment of visual literacy and spatial ability will require the cooperation of anatomy classroom instructors. Working with classroom instructors to ensure exam items are assessing visual skills authentically will provide much more valuable variable in future studies. Authentic assessment of visual skills in anatomy might consist of exam items which require mental rotation or making inferences from images. Changing exams to require more visual thinking should provide benefits to instructors as well as benefitting this research plan.

Non-cognitive factors (e.g., motivation, peer support, and financial support) have been shown to be important determinants of student success in higher education (Robbins et al. 2004). It is possible there were non-cognitive factors, especially motivational factors underlying some of the unexpected changes seen in student study habits. Adding survey questions to assess the non-cognitive components of a student's study strategies will provide a wealth of new information about anatomy students.

Qualitative data collected from students may help elucidate some of the questions raised by this research. For example, in Figure 7.4 the highest performing students in the course final grades can be grouped into high and low-visual learning score groups, but both groups performed equally well in the course. From the survey data, it is unclear what other differences these two groups may have. Both groups reported using the same amount of time studying and the same amount of previous experience in anatomy courses. There may be other underlying factors explaining this difference, but the survey did not ask those questions. An interview or focus group would allow students the opportunity for more open-ended discussion that may reveal some additional variables that were not in the survey.

Final Summary

This dissertation supports the hypothesis that visual skills (spatial ability and visual literacy) are important in anatomy education. Students enjoyed learning how to apply visual learning techniques to their anatomy courses, but many of them lack the ability to do so without more instruction. Adding visual learning to anatomy courses (and exams) is a goal that can lead to higher student satisfaction, improved visual literacy, and improved metacognition. While instructors may struggle with incorporating visual learning into an established course, online resources (such as *Draw It to Know It*) can help. Additionally, adding course assessments that require higher-level visual thinking will increase students' awareness of their own visual thinking, and increase student openness to new learning techniques. Visual literacy is necessary to all fields of medicine (the goal of most anatomy students), but to many instructors and practitioners, it has become second nature. However, the slow accumulation of visual literacy by practice in a discipline is often inadequate, and may leave behind many students who fail to grasp it. Visual literacy should not be treated as skill only the most expert members of a field have, it should be taught to all students from the beginning of their education in anatomy.

APPENDIX A: Survey Design, Validation, and Sample Surveys

Surveys were developed using methods previously established (Fowler, 1995) and piloted in a smaller, undergraduate anatomy class before being used in the dissertation research. After piloting the survey, students were asked for feedback on their interpretation of the questions. This feedback was then applied to make questions about study skills more clear and relevant to the students. Additionally, the survey was discussed and edited with several anatomy faculty members to ensure the questions being used aligned with the courses being taught. The same survey has also been used in other studies of undergraduates over several semesters, and responses in all categories are statistically consistent between years, indicating a high level of survey reliability (Barger 2012, Barger and Husmann 2013). Cronbach's alpha was also calculated on the combined undergraduate and medical student population at 0.767 indicating a good level of reliability. While undergraduate students and medical students are different groups, this study focuses on students in their first year of medical school, many of which are entering medical school immediately after completing their bachelor's degree. It is unlikely that medical students would interpret the questions differently than the undergraduates on whom the survey was validated. All of the surveys included Likert scale and categorical questions, as well as boxes for open-ended comments. Questions covered three general themes: student study habits (use of text, notes, learning exercises, etc.), attendance and attitudes (confidence, integration, etc.), and basic demographics and background information (previous coursework, experience, etc.). The demographic sections were omitted from later surveys to reduce the time burden of taking the survey, and the demographic differences in students did not have any apparent effect on the variables being studied. For the purpose of this dissertation, learning exercises are composed of tables, timelines, etc. usually produced by the instructor and given to the students for them to use as additional study resources. All comment boxes were located within the section on student study habits. No students chose to complete the open-ended questions or provide additional comments about their study habits.

In the sample survey provided below, the penultimate section dealing with visual approaches to learning was added only for the research facets discussed in chapters 5-6. The research in chapter 4 did not include a specific inventory of student attitudes toward visual learning. The final section on the sample survey dealing with specific instructional techniques was only present on the survey used in chapter 7.

STUDY SKILLS SURVEY (SAMPLE)

This survey has a number of questions about your attitudes towards your studies and your usual way of studying *outside* of lab time for the A215 lab exams.

There is no *right* way of studying. It depends on what suits your own style and the course you are studying. It is accordingly important that you answer each question as honestly as you can.

The following section deals specifically with methods of studying you used to prepare for A215 lab exams. Please consider only the studying you did outside of lab. You will rate each item with the following scale.

A— this item is *always* or *almost always* true of me

B— this item is *frequently* true of me

C— this item is true of me about *half the time*

D— this item is *sometimes* true of me

E— this item is *never* or *only rarely* true of me

I used the textbook (Human Anatomy, Michael McKinley and Valerie Dean O’Loughlin) for **lab** studying by:

8. Reading the text or tables

A B C D E

9. Reviewing the figures
   A B C D E
10. Answering practice questions in the chapter reviews.
   A B C D E

I used the A215 website outside of **lab** for:

11. Virtual microscope
   A B C D E

I used these other study aids for **lab** studying:

12. Anatomy coloring book
   A B C D E
13. Flashcards
   A B C D E

I made my own study tools for **lab**:

14. Drawings or diagrams
   A B C D E
15. Tables of information
   A B C D E
16. Flashcards
   A B C D E

Collaborative learning:

17. I studied A215 **lab** with one other person.
   A B C D E
18. I studied A215 **lab** in a group of with two or more other A215 students.
   A B C D E

The next section considers general study habits, and class attendance. Each item has its own scale, so please read carefully.

19. About how many hours per week did you spend studying for **lab** exams outside of lab time?

   A: 0-1 B: 2-3 C: 4-5 D: 6-7 E: more than 7

20. Which statement best describes your *lecture* attendance?
    A. I was at every session.
    B. I missed one or two sessions.
    C. I missed more than three, but attended over half the sessions.
    D. I attended less than half the time.
    E. I rarely attended

21. Which statement best describes your *lab* attendance?
    A. I was at every session.
    B. I missed one or two sessions.
    C. I missed more than three, but attended over half the sessions.
    D. I attended less than half the time.
    E. I rarely attended

22. In your experience, how useful was it to study lecture and lab material together?
    A B C D E
    Very useful………………………………………………………………..Not at all useful

23. What grade do you expect to receive in this course?
    A. A
    B. B
    C. C
    D. D
    E. F

The next section concerns your specific use of visual approaches to studying and learning new things.

A— this item is *always* or *almost always* true of me

B— this item is *frequently* true of me

C— this item is true of me about *half the time*

D— this item is *sometimes* true of me

E— this item is *never* or *only rarely* true of me

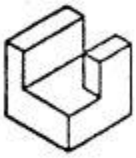
24. When learning something new I will look at pictures and diagrams first.
    A B C D E
25. When planning a route to a new place, I prefer to look at a map.
    A B C D E
26. When giving directions to a friend, I would prefer to draw a map.
    A B C D E
27. If a physician is explaining a medical diagnosis, I would prefer to see a picture or model of the problem.
    A B C D E
28. When planning a speech or paper, I use an outline.
    A B C D E
29. When delivering a speech I prefer to use pictures and diagrams to explain key points.
    A B C D E
30. I believe I am a visual learner
    A. Strongly agree
    B. Agree
    C. Neither agree nor disagree
    D. Disagree
    E. Strongly disagree

The next section concerns your experiences with the specific teaching methods of this course. (OMIT FOR FIRST SURVEY)

1. The drawing lessons improved my learning of anatomy/histology.
    - A. Strongly agree
    - B. Agree
    - C. Neither agree nor disagree
    - D. Disagree
    - E. Strongly disagree
2. The drawing lessons improved my spatial abilities.
    - A. Strongly agree
    - B. Agree
    - C. Neither agree nor disagree
    - D. Disagree
    - E. Strongly disagree
3. The drawing lessons lead to an increase in visual studying for me.
    - A. Strongly agree
    - B. Agree
    - C. Neither agree nor disagree
    - D. Disagree
    - E. Strongly disagree
4. I will use visual approaches in studying for future courses.
    - A. Strongly agree
    - B. Agree
    - C. Neither agree nor disagree
    - D. Disagree
    - E. Strongly disagree
5. I liked the drawing lessons.
    - A. Strongly agree
    - B. Agree
    - C. Neither agree nor disagree
    - D. Disagree
    - E. Strongly disagree

APPENDIX B: Mental Rotation Test

The mental rotation test (Purdue SVT) was published in 1997 by Bodner and Guay, and was used with permission.



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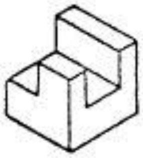

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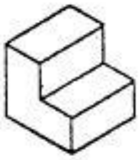

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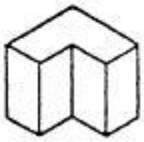

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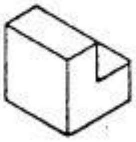
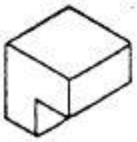


C



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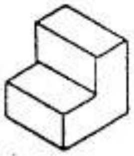

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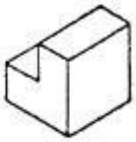
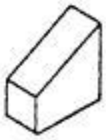


Answers A. B. C. and E are wrong. Only drawing D looks like the object after it hsa been rotated. Remember that each question has only one correct answer.

Now look at the example shown below and try to select the drawing that looks like the object in the correct position when the given rotation is applied

AS



IS ROTATED TO

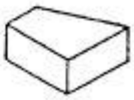
A

B

C

D

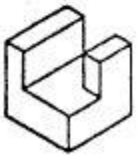
E



Note that the rotation in this example is more complex. The correct answer for this example is B.

DIRECTIONS

This test consists of 20 questions designed to see how well you can visualize the rotation of three-dimensional objects. An example of the type of question included in this test is shown below.



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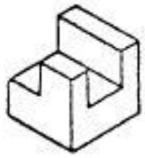

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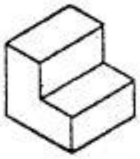
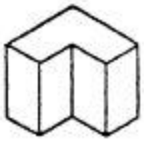


IS ROTATED TO

A



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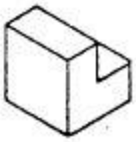

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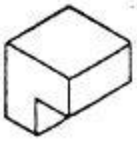

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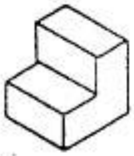
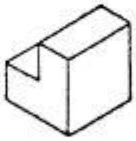


E



For each question, you should:

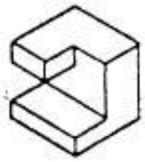
I. Study how the object in the top line of the question is rotated.

II. Picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner.

III. Select from among the five drawings (A, B, C, D, or E) given in tbe bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?

1



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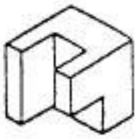

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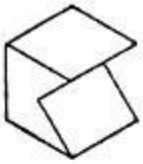
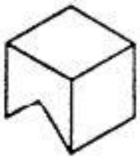


IS ROTATED TO

A



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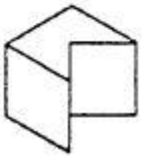

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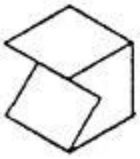

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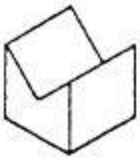

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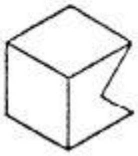

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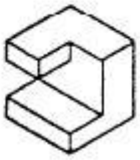

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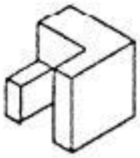

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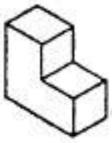

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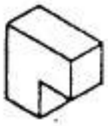

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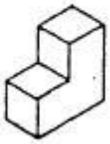

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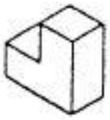

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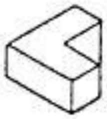

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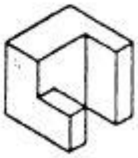

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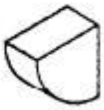

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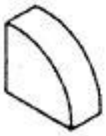

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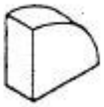

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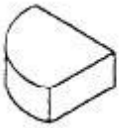

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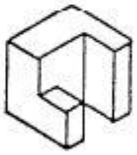

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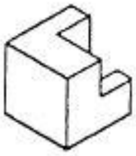

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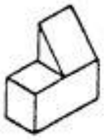

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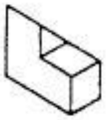

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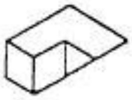

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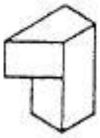

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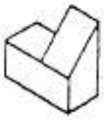

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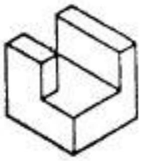

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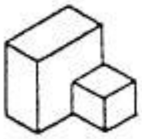

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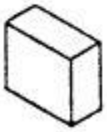

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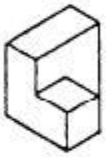

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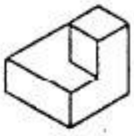

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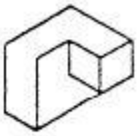

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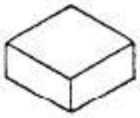

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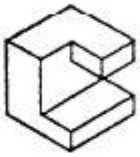

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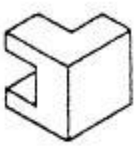

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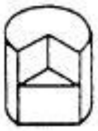

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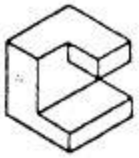
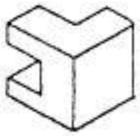
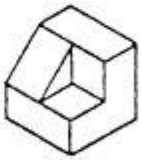
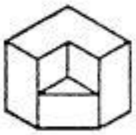
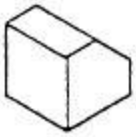
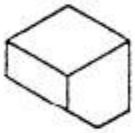
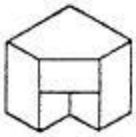
7  IS ROTATED TO 

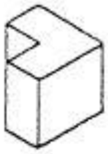
AS  IS ROTATED TO

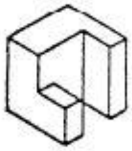
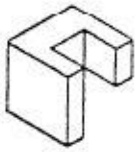
A 

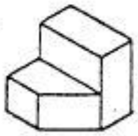
B 

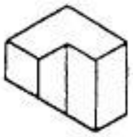
C 

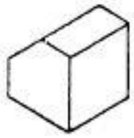
D 

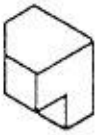
E 

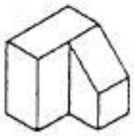
8  IS ROTATED TO 

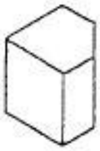
AS  IS ROTATED TO

A 

B 

C 

D 

E 

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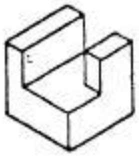

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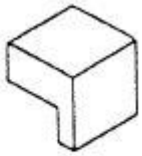

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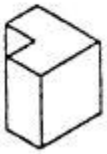

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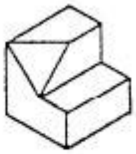

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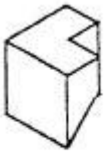

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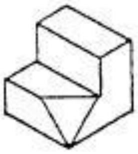

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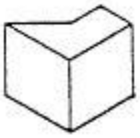

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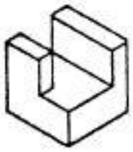

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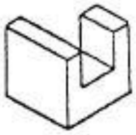

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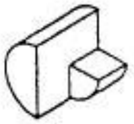

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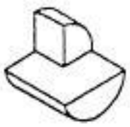

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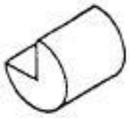

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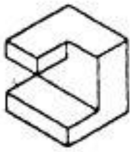

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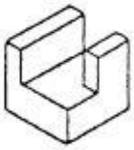

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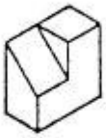

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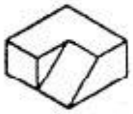

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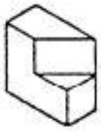

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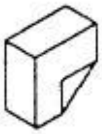

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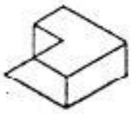

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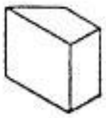

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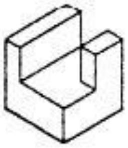

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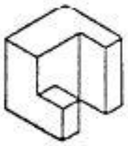

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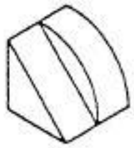

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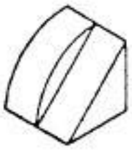

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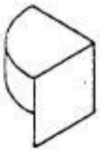

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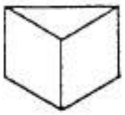

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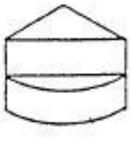

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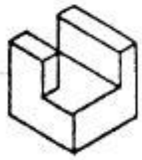

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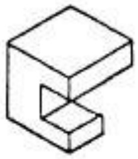

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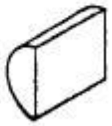

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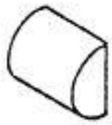

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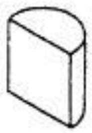

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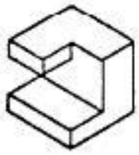

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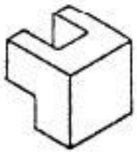

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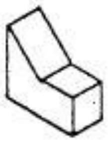

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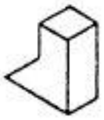

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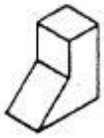

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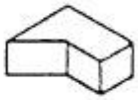

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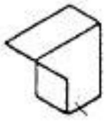

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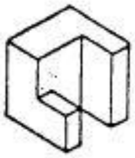

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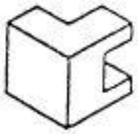

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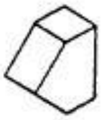

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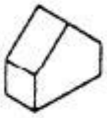

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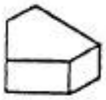

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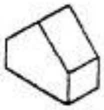

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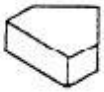

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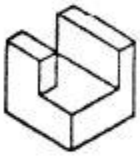

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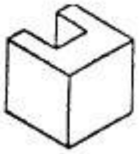

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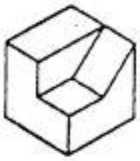

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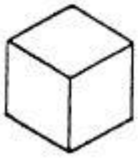

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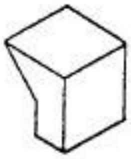

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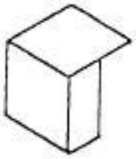
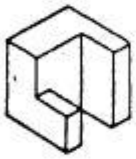
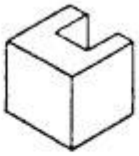


17  IS ROTATED TO 

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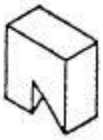

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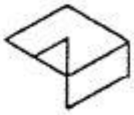

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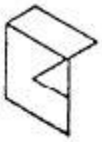

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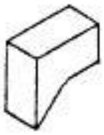
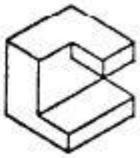
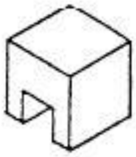


18  IS ROTATED TO 

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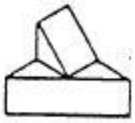

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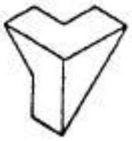

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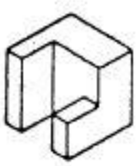
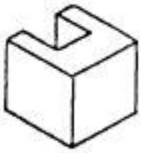
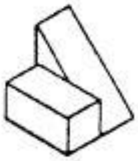
19  IS ROTATED TO 

AS  IS ROTATED TO

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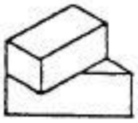

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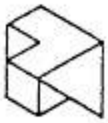

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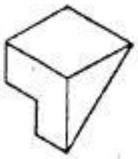

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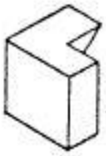
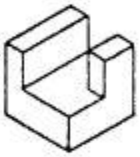
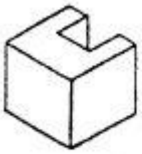
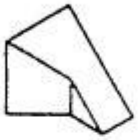


20  IS ROTATED TO 

AS  IS ROTATED TO

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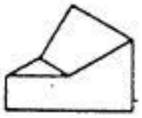

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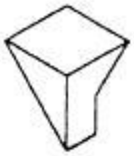

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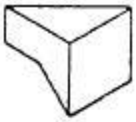

APPENDIX C: Course Syllabus Excerpts

The syllabus excerpts provided here cover the study skills and techniques students frequently recommend to students. Usually, this brief syllabus paragraph is the only instruction in study skills students receive.

A215-

ANATOMY A215 (BASIC HUMAN ANATOMY) SYLLABUS OF INFORMATION AND POLICIES FALL 2015

Once you come to lecture, we will apply and reinforce the material you learned in the podcast. We then will discuss the clinical applications of the anatomical region in question and learn new material. Thus, your preparation ahead of time (by watching the podcasts and doing your reading) will allow us to discuss the interesting applications of anatomy! Note that all questions on the lecture exams will deal with material covered in the podcasts, your lecture outlines, and in lecture. Thus, it is to your advantage **prepare ahead of time and to attend lectures. You will understand the material much better during lecture if you read the textbook pages indicated on your schedule. In particular, study the figures in the book; they are generally very good and will help you understand the material** (emphasis added)**.**

P215-

P215 Basic Human Physiology Spring 2016

Lectures may begin with conceptual questions that emphasize material important for exams. It is important that you are able to answer these questions on your own. If you cannot that means you should either ask questions in class, in office hours or via email. If a student misses lecture for any reason, they are responsible for obtaining copies of the lecture notes from another student. Questions about the content of those notes are welcome, but realize that **nothing can replace the learning process of taking your own notes**. To be successful in this class, students will **need to fully understand the concepts**. **Attempts to memorize the material will generally not achieve good results** (emphasis added).

A550-

SYLLABUS – Fall 2015 GROSS HUMAN ANATOMY 1 (ANAT-A550) –

STUDY TIPS FOR GROSS ANATOMY: 1. We strongly encourage you to study together and work in groups when preparing for both lecture and lab. Discuss complex topics and quiz each other. Working in a group will allow all involved to better understand the material and help clarify any misconceptions. 2. Make sure you examine and study ALL of the bodies in the gross lab. As you will learn, variation is considerable and structures can look completely different in different bodies. 3. Do NOT try to "cram" for the exams. Lecture exams ask you not only to identify material, but to apply and synthesize your knowledge. Instead, try to study a little bit every day. 4. If you have questions, or aren't doing as well as you'd like, please see one of the instructors right away! We want you to succeed and we are here to help. However, we do not know if you need help unless you come and speak with us! 5. In lab, make sure you come prepared to lab (read dissector ahead of time and review atlas images) and expect to spend the full time in lab, and use the resources available to you in lab (e.g., AIs, sample images and dissection quizzes, etc.).

P531-

Syllabus P531-P532: MEDICAL PHYSIOLOGY Fall 2014

The goal of this class is to facilitate your learning of medical physiology. To this end, the course is designed to emphasize active student learning by integrating class session, discussion, problem-based learning exercises, and laboratories. Class sessions will involve periods of explanation interspersed with problem solving and discussion. The time will be split roughly 50/50 between these two modes of learning. We encourage questions at any time. Questions before and after class, during office hours, and via e-mail, are encouraged as well. Your teachers do not expect you to know everything. We certainly don't! We encourage you to voice your confusions to us; we learn as much from you as you do from us. Part of the respect rule is to make the classroom learning environment as safe and open as possible, so you can relax and feel free to be confused and to work on those items that are confusing. We have all worked to develop teaching styles and methods that best meet the needs of our students. There will be periodic opportunities to voice your opinions (which are welcome at any time) about things that may or may not be working for you in the classroom. We will try to make any change that we can that will help facilitate your learning.

APPENDIX D: IRB Documents

These sample documents are provided for informational purposes only. Slight wording changes may exist between various versions of the documents.

IRB approval numbers: Study skills- 1010002079

Illustration teaching- 1301010307

DITKI- 1310535940

INDIANA UNIVERSITY BLOOMINGTON

INFORMED CONSENT STATEMENT

Examining Study Skills in Anatomy & Physiology

You are invited to participate in a research study analyzing the effectiveness of a study skills course on anatomy students. You were selected as a possible subject because you are enrolled in A215, P215, A550, or P531. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

The study is being conducted by Bradley Barger and Polly Husmann, both of whom are graduate students, in Anatomy and Anthropology, respectively. Since one of the researchers may be an instructor for your class neither of them will know if you have participated in this research until after all semester grades are final and have been reported to the Registrar.

STUDY PURPOSE

The purpose of this study is to determine what kind of study methods are employed by students, and which methods, if any, lead to higher final grades.

NUMBER OF PEOPLE TAKING PART IN THE STUDY:

All students enrolled in A215, P215, A550, or P531 will be asked to participate in the study.

PROCEDURES FOR THE STUDY:

If you agree to be in the study, you will complete a survey, expected to take no more than ten minutes and grant the investigators permission to compare the responses to this survey to your course grades. After the comparison between your survey and course grades has been completed all identifying data will be removed.

If you are a student in A215 you will complete this survey twice (once at the beginning of the semester and again at the end of the semester); students in all other courses will complete this survey only once at the end of the semester.

RISKS OF TAKING PART IN THE STUDY:

There are no foreseeable risks or discomforts for any of the procedures to be used in this study.

BENEFITS OF TAKING PART IN THE STUDY:

By participating in this study, you will help the principal investigators determine which study habits are the most useful for studying in anatomy and physiology courses. This information will help future students in the listed courses.

ALTERNATIVES TO TAKING PART IN THE STUDY:

Instead of being in the study, you have the option to not to participate. If you choose not to participate you can work on other course materials during the 10 minutes that the survey is being completed in the classroom. Your participation in this study is voluntary. There is no penalty if you decide not to participate.

CONFIDENTIALITY:

Efforts will be made to keep your personal information confidential. We cannot guarantee absolute confidentiality, although we will not report names or identification numbers. Your personal information may be disclosed if required by law. Any published data will be de-identified, and presented only in aggregate. Any saved documents will be de-identified as well.

Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigator and his/her research associates, the IUB Institutional Review Board or its designees, and (as allowed by law) state or federal agencies, specifically the Office for Human Research Protections (OHRP).

PAYMENT

You will not receive payment for taking part in this study.

CONTACTS FOR QUESTIONS OR PROBLEMS

For questions about the study or a research-related concern you may contact Audra Schutte.

For questions about your rights as a research participant or to discuss problems, complaints or concerns about a research study, or to obtain information, or offer input, contact the IUB Human Subjects office, 530 E Kirkwood Ave, Carmichael Center, 203, Bloomington IN 47408, 812-855-3067 or by email at iub_hsc@indiana.edu

VOLUNTARY NATURE OF STUDY

Your participation in this study is voluntary; you may decline to participate without penalty. Your grade for the course is in no way influenced by whether or not you choose to participate. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will not be used in this study. Your decision whether or not to participate in this study will not affect your current or future relations with the investigator(s).

SUBJECT'S CONSENT

In consideration of all of the above, I give my consent to participate in this research study.

I will be given a copy of this informed consent document to keep for my records. I agree to take part in this study.

Subject's Printed Name:____

Subject's Signature:________________________________**Date**:______________

(must be dated by the subject)

Indiana University - Bloomington
(recruitment script)
Examining Study Skills in Anatomy & Physiology

You are invited to participate in a research study that aims at improving the learning of anatomy and physiology. This study is being conducted by Bradley Barger and Polly Husmann, two graduate students in Anatomy and Anthropology, one of these individuals may be an instructor for your class, but neither of them will know about your participation in this study until after the semester has ended and all grades have been reported to the Registrar. The goal of this research study is to investigate the methods students use to learn in anatomy and physiology classes. One of the aims of this study is to determine which, if any, methods lead to higher final grades.

Your participation in this study requires only that you fill out a brief survey about your methods of studying for this course. In signing this consent statement, you also agree to give permission for the researchers to use your survey data to compile lists of study activities and compare these lists to your final grades. All personal information will be removed, and you will not be personally identifiable in any way after the grade comparison. If this research is published, no personal information will be presented.

I will distribute and collect this consent form, so that your instructor will not know if you have participated until after the course is finished and final grades have been entered.

The researchers will preserve confidentiality by removing identifiable information including student ID numbers from all the data. The analysis of the data will focus on group patterns that will be described in aggregate terms.

Your participation in this study is voluntary. There is no penalty for not participating. If you decide to participate, you may withdraw from the study at any time. After completion of the study, the researchers will be happy to discuss the results with you.

Should you have any questions while the study is in progress, or should you decide any time to withdraw, please contact me, Audra Schutte. After the study is over and your grades have been posted, either Bradley or Polly will be willing to answer any questions, or withdraw your data, if you wish.

If you are willing to participate in the study, please sign one of the two copies of the consent form and return it to me. The second copy is for you to keep for reference. If you feel you have not been treated according to the descriptions in this form, or that your rights as a participant have not been honored during the course of this project, you may contact the Human Subjects Committee, Indiana University, 509 E. 3rd Street, Bloomington, IN 47401, (812) 855-3067, or email at iub_hsc@indiana.edu

We appreciate your considering participation in this research and thus enabling us to improve instruction in anatomy and physiology courses.

Thank you.

APPENDIX E: SPSS outputs

These tables are placed here for reference. Each table is too large to fit in the relevant chapter, but each is referenced in the appropriate places in the above text.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.138	19.761	19.761	5.138	19.761	19.761
2	3.392	13.047	32.809	3.392	13.047	32.809
3	1.835	7.058	39.867	1.835	7.058	39.867
4	1.556	5.986	45.852	1.556	5.986	45.852
5	1.531	5.888	51.741	1.531	5.888	51.741
6	1.235	4.750	56.490	1.235	4.750	56.490
7	1.183	4.551	61.041	1.183	4.551	61.041
8	1.103	4.240	65.282	1.103	4.240	65.282
9	.970	3.731	69.013			
10	.919	3.534	72.547			
11	.879	3.382	75.929			
12	.729	2.805	78.734			
13	.619	2.381	81.115			
14	.597	2.296	83.411			
15	.583	2.243	85.654			
16	.551	2.119	87.772			
17	.540	2.077	89.849			
18	.416	1.601	91.450			
19	.380	1.460	92.910			
20	.343	1.319	94.229			
21	.326	1.252	95.481			
22	.293	1.128	96.608			
23	.266	1.021	97.630			
24	.244	.939	98.569			
25	.202	.777	99.346			
26	.170	.654	100.000			

Table E.1- Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component							
	1	2	3	4	5			
Text book text	.340	.522	.077	.457	.348			
text bookfigures	.195	.659	.070	.329	.226			
textbook website	.513	.335	-.103	.022	.437			
practice question	.694	-.308	.016	.223	-.014			
virtual microscope	.102	.636	.001	.165	-.293			
virtual labs	.363	.322	-.103	-.139	-.253			
learning ex	.579	-.265	-.165	-.129	.054			
lecture notes	.368	.175	-.279	.390	-.366			
coloring book	.661	-.313	-.122	.013	-.129			
flashcards	.698	-.132	-.163	-.107	-.178			
other book	.587	-.354	-.162	-.013	.020			
other website	.395	.378	-.288	-.029	.342			
computer software	.516	.233	-.071	.004	.201			
made drawings	.304	.558	.164	-.285	-.050			
made tables	.587	.189	.135	.001	-.129			
made flashcards	.591	.109	-.095	-.292	.017			
studied with one	.259	.417	.196	-.513	-.003			
studied with two or more	.591	-.123	-.085	-.354	.153			
hours	-.014	-.468	.009	.109	.334			
lecture attend	-.341	.427	.470	-.328	.230			
lab attend	.287	-.065	.181	-.281	-.434			
lab and lecture together	.464	-.423	.501	.105	.125			
L&L	.425	-.246	.625	.139	-.061			
L&L	.342	-.288	.478	.246	.126			
Expected grade	.124	.362	.088	.342	-.473			
studied enough	.073	.156	.557	-.010	-.143			

Table E.2- Extraction Method: Principal Component Analysis.
The three smallest components have been removed from this table for space considerations.

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Curriculum Vitae

J. Bradley Barger

Education-

Indiana University (IU)

PhD in Anatomy and Cell Biology

Completed: July 2016

Primary Advisor: Valerie O'Loughlin

Dissertation: *Visual Learning in Anatomy*

University of Kansas (KU), Lawrence, KS

MA - Entomology, August 2006

BA - Organismal Biology, May 2003

Publications-

Husmann, P. R., Barger, J. B. and Schutte, A. F. (2015). "Study skills in anatomy and physiology: Is there a difference?". *Anat Sci Ed*. doi: 10.1002/ase.1522.

Barger, J. B. (2010). "Teaching from the Trenches: How my experiences as a teacher and as an anatomy education PhD student have changed the way I teach". *HAPS-Educator,* 15(1), 22-25.

Published Abstracts-

Barger, J. B. (2014). "Using in-class drawing exercises to teach anatomy and visual skills" (534.10). *The FASEB Journal*, 28.

Barger, J. B., & Husmann, P. (2013). "A comparison of medical student and undergrad study skills in anatomy lab courses". *The FASEB Journal*, 27.

Barger, J. B. (2012). "How do undergraduate students study for anatomy, and does it matter?" *The FASEB Journal,* 26.

Husmann, P. R., & Barger, J. B. (2011). "Medical Student Study Skills in Anatomy and Physiology: Is There a Difference?" *The FASEB Journal*, 25.

Invited Lectures-

HAPS Synapse 2015 (May 30, 2015 San Antonio, TX)- "Visual Literacy in Anatomy"

AAA Education Platform 2014 (April 28, 2014 San Diego, CA)- "In-Class Drawing Exercises to Teach Visual Skills"

Other presentations-

I have been an active member of the Human Anatomy and Physiology Society (HAPS) throughout my graduate career. I have presented at least one workshop at each annual meeting since 2011. These workshops have focused on the application of in-class drawing as a way of helping students learn visual literacy.

Teaching Experience-

Indiana University

Human Gross Anatomy; ANAT-A550 (Summer 2010-Present)

- Position: Associate Instructor
- Duties: run lab sessions; create and grade lab exams; perform cadaver prosection

Basic Human Anatomy; ANAT-A215 (Fall 2009-Present)

- Position: Associate Instructor
- Duties: deliver lab lectures; guide student lab work

Improving Study Skills in Anatomy: MSCI-M100 (Fall 2014-Spring 2015)

- Position: Instructor of Record
- Duties: develop original course design to teach visual skills to undergraduates enrolled in basic

human anatomy; create weekly assignments and assessments aligned with the topics covered by the anatomy course

Medical Neuroscience: MSCI-M555 (Spring 2012)

- Position: Associate Instructor
- Duties: deliver lab lectures; guide student lab work; create and grade lab exams

Histology: ANAT-A560 (Fall 2011)

- Position: Associate Instructor
- Duties: deliver lab lectures; guide student lab work including optical and virtual microscopy; create and grade lab exams

Ivy Tech Community College (position for all: Instructor of Record)

Anatomy and Physiology; APHY 101 (Fall 2008-Spring 2013)

Anatomy and Physiology; APHY 101 Hybrid/Online course (Spring 2009-Spring 2013)

- Special duties: develop original content including course syllabus, online presentations and learning exercises, and a series of narrated videos of the course's anatomical models

Johnson County Community College (position for all: Instructor of Record)

Principles of Biology Lecture (Spring 2007-Summer 2007)

Principles of Biology Lab (Fall 2006)

Human Anatomy (Fall 2006)

Anatomy and Physiology (Spring 2007)

University of Kansas (Graduate Teaching 2003-2005, Undergraduate Teaching Assistant 2002-2003)

Human anatomy laboratory course (Spring 2004-Fall 2005)

Introductory biology laboratory course (Fall 2002-Fall 2003)

Research Experience-

Indiana University (Summer 2010- Present):

I have developed a survey instrument that examines student study habits outside the undergraduate anatomy classroom and the use of visual study skills by the student. I have also collected mental rotation scores and course grades from students (IRB Approved). In some courses, pedagogical interventions were used (drawing lessons, new software), and changes in student learning and visual literacy metrics were collected. These data were then compared to physiology students, medical anatomy students at two different institutions, and across semesters.

University of Kansas (Fall 2001-Summer 2006):

- Dissection of human cadavers for anatomy instruction course.
- Collection and lab experimentation on two species of hard ticks: (family Ixodidae) *Amblyomma americanum* and *Dermacentor variabils.*
- Designed and conducted biomechanical experiments on larval antlions (*Myrmeleon crudelis)*, and their pitfall traps.

Awards-

2015 Outstanding Associate Instructor, Indiana University School of Medicine, Medical Sciences

2014 Lippincott Williams Wilkins/AAA Education Research Scholarship

2012 HAPS graduate student travel award

Professional service-

HAPS (2011-present)

I have been an active member of the Human Anatomy and Physiology Society for over four years, serving on several committees. Most recently I have served as a reviewer of submissions to the *HAPS Educator* publication.