METACOGNITION IN ANATOMICAL SCIENCES EDUCATION

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DEDICATION

This dissertation is dedicated to my mom, Hana Cale, for her unconditional love, support, encouragement, and sacrifice. Absolutely none of my achievements would have been possible without you. I am eternally grateful to you and love you always, Mom!

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METACOGNITION IN ANATOMICAL SCIENCES EDUCATION

Metacognition, the ability to self-regulate one's learning and performance, is well-known to provide numerous academic and professional benefits for students, educators, and clinicians. However, few studies have studied metacognition specifically in the context of anatomical sciences education. Therefore, the overarching purpose of this dissertation was to explore the metacognition of students and educators who are learning and teaching the anatomical sciences.

This dissertation investigated the metacognition of allied health students (physical therapy, physician assistant, and occupational therapy; n=109), first-year medical students (n=1802), and anatomy educators (faculty, associate instructors, and teaching assistants; n=13) in anatomy courses through three multiple-methods studies. Quantitative data were collected using assessment data and either the Metacognition Awareness Inventory (MAI), Practice-Based Learning and Improvement (PBLI) assignments, or Teacher Metacognition Inventory (TMI). These data were then analyzed using the appropriate descriptive and inferential statistics. Qualitative data were also collected through reflective writing activities (e.g., online discussion boards or reflective journals) and analyzed using thematic or framework analysis.

Overall, both students and educators improved their metacognition across a semester of either learning or teaching anatomy, with certain subgroups demonstrating greater metacognitive ability or growth than others. Higher performing allied health and medical students were both more accurate at predicting their exam performances compared to their lower performing peers. Faculty also demonstrated the greatest teaching-specific metacognition, though teaching assistants exhibited the greatest growth in their teaching-specific metacognition. These improvements were primarily in their reflective ability and awareness of personal strengths and weaknesses as teachers. Several notable themes relating to metacognition were also identified such as student willingness to monitor learning diminishing over time due to competing academic or professional commitments. Additionally, novice educators were more inwardly-focused on personal traits and content mastery, whereas experienced educators were more outwardly-focused on interpersonal factors (e.g., student rapport and inclusive language).

These insights into the metacognition of both students and educators can inform how to best support and improve teaching and learning in the anatomical sciences. Given the significance of metacognition, it may be beneficial to incorporate educational activities that can support the metacognition of both students and educators, simultaneously.

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LIST OF ABBREVIATIONS

AI	Associate Instructor
COVID-19	Coronavirus Disease 2019
DEI	Diversity, Equity, and Inclusion
DPT	Doctor of Physical Therapy
HS	Human Structure
IUSM	Indiana University School of Medicine
LASSI	Learning and Study Strategies Inventory
LCME	Liaison Committee on Medical Education
MACH	Methods, Analogies, Context, How
MAI	Metacognitive Awareness Inventory
MAISE	Metacognitive Awareness Inventory for Surgical Educators
MAIT	Metacognitive Awareness Inventory for Teachers
MANOVA	Multivariate Analysis of Variance
ME	Metacognitive Experience
MK	Metacognitive Knowledge
MKaS	Metacognitive Knowledge about Self
MPAS	Master of Physician Assistant Studies
MR	Metacognitive Regulation
NBME	National Board of Medical Examiners
OT	Occupational Therapy/Occupational Therapist
OTD	Doctor of Occupational Therapy
PA	Physician Assistant

PBLI	Practice-Based Learning and Improvement
PT	Physical Therapy/Physical Therapist
REDCap	Research Electronic Data Capture
SMART	Specific, Measurable, Attainable, Relevant, Time-Bound
SPSS	Statistical Product and Service Solutions
TA	Teaching Assistant
TBL	Team Based Learning
TME	Teacher Metacognitive Experience
TMI	Teacher Metacognition Inventory
TMK	Teacher Metacognitive Knowledge
TMR	Teacher Metacognitive Regulation
UiM	Underrepresented in Medicine

CHAPTER 1. INTRODUCTION

1.1 Statement of Problem

The anatomical sciences are often regarded as one of the more challenging subjects to learn (Bati et al., 2013; Gutice et al., 2015). When presented with the numerous anatomical structures, relationships, terms, and concepts that comprise the human body, students may need to reevaluate and adapt their study strategies. The inherent challenge of learning the anatomical sciences is further increased by the novel methods through which the anatomical sciences are taught and assessed (Middendorf and Pace, 2004). For example, normal or pathological anatomical variations encountered during human cadaveric dissection or virtual microscopy may require both students and educators to re-evaluate their existing anatomical knowledge, adapt how they approach learning and teaching the material, and accept a small degree of uncertainty overall. Moreover, the anatomical sciences are considered foundational in medicine and often placed at the beginning of medical professional curricula. As a result, newly matriculated students who are unaccustomed to the pace and rigor of medical education often struggle to adapt their existing learning strategies to the unfamiliar obstacles. When facing novel challenges such as these, students may engage in metacognition, the process of monitoring and controlling one's own thought processes, to adapt to and overcome their new educational demands (Flavell, 1979; Dye and Stanton, 2017; Stanton et al., 2021).

Metacognition, more simply described as "thinking about one's own thinking", is the ability to plan, monitor, and evaluate one's learning and performance through control of one's thought processes (Flavell, 1979; Lai, 2011). Since its original description by John Flavell in 1979, the concept of metacognition has evolved significantly, largely due to the contributions of other metacognition researchers that followed (Brown, 1977; Flavell, 1979; Pressley et al., 1989; Kuhn, 1999; Tarricone, 2011). Numerous studies have also further explored metacognition in a variety of contexts, identified the many benefits of improved metacognition, and developed novel methods for enhancing metacognition (Naug et al., 2011; Chew et al., 2016; Stanton et al., 2019; Amin et al., 2020; Honeycutt et al., 2021; Menekse et al., 2022). Across multiple populations and contexts, metacognition has been shown to improve critical thinking, enhance learning, improve task performance, increase the accuracy of self-evaluation, and foster growth mindsets (Naminule and Corebima, 2018; Lazendic-Galloway et al., 2019; Stanton et al., 2019; Menekse et al., 2022; Martin-Piedra et al., 2023). More specifically for students, metacognition can also support deeper learning and improve performance on assignments, projects, and standardized tests (Chang, 2021; Honeycutt et al., 2021; Menekse et al., 2022). Similarly, metacognition has also been associated with improved patient safety, clinical decision-making, and diagnostic error occurrence in clinical professionals as well as more effective and dynamic teaching in educators (Kuiper and Pesut, 2004; Ali and Yasmeen, 2019; Royce et al., 2019; Siqueira et al., 2020).

Currently, one of the most widely accepted models of metacognition is Flavell's revised model, which includes three dimensions: (1) metacognitive knowledge (i.e., an individual's knowledge of their own strengths and weaknesses), (2) metacognitive regulation (i.e., an individual's ability to monitor, evaluate, and regulate their learning and performance), and (3) metacognitive experience (i.e., emotions and judgments such as confidence or satisfaction that occur in real-time during task performance) (Flavell et al., 2002). Each of these dimensions will be explored in greater detail in Chapter 2: Review of the Literature.

Metacognition in the context of education is well documented in the existing literature. The different elements of metacognition can be classified as either domain-general (i.e., applicable across multiple disciplines) or domain-specific (i.e., specific to a single discipline) (Lai, 2011; Zohar and Barzilai, 2013). Therefore some, but not all currently known metacognitive principles may be transferable to the anatomical sciences. Unfortunately, due to the lack of metacognition literature specific to the anatomical sciences, it is difficult to determine which principles are generalizable. Due to its unique requirements such as "bell-ringer"-style practical exams and human cadaver-based laboratory sessions, students and educators of the anatomical sciences may even engage in metacognition in a manner that has yet to be documented and understood. Given that the metacognitive abilities of students and educators are often closely linked due to metacognitive educators being more adept at training their students to be metacognitive (Wilson et al., 2010), the metacognition of both groups should be investigated in tandem. Therefore, further exploration of the metacognitive practices of both students and educators of the anatomical sciences is warranted to fill this gap in the literature.

1.2 Purpose of Study

Although the metacognition literature specific to the anatomical sciences is limited, existing evidence from medical education and higher education as a whole suggests both students and educators of the anatomical sciences can derive significant benefits from improved metacognition (Kuiper and Pesut, 2004; Ali and Yasmeen, 2019;

Siqueira et al., 2020; Chang, 2021; Honeycutt et al., 2021; Menekse et al., 2022). The studies described in this dissertation were designed to explore the metacognition of both students and educators in the context of anatomical sciences education. The first study, *Metacognition in Allied Health Students*, investigated the metacognitive practices of first-year allied health students (Doctor of Physical Therapy, Master of Physician Assistant Studies, and Doctor of Occupational Therapy) in a graduate-level gross anatomy course. This study applied a multiple-methods approach involving quantitative analysis of survey responses and qualitative analysis of asynchronous online discussion board responses. Through the discussion board responses, we also determined the students' metacognitive foci, defined here as the topic an individual focuses on when engaging in metacognitive thought processes (e.g., their study habits, exam performances, overall learning, etc.). The findings from this study provide insight into how allied health students practice and alter their metacognition as they progress through their first graduate-level anatomy course. The second study, *Metacognition in First-Year Medical Students*, retrospectively evaluated the metacognitive practices of undergraduate medical students before and after their first professional-level integrated anatomy exam. This study also compared the metacognition of students who initially failed and repeated their gross anatomy course (repeating) and students who successfully passed the course on their initial attempt (non-repeating). The insights gained from this multiple-methods study can help anatomy educators better identify struggling students based on their study habits prior to course failure. Lastly, the third study, *Metacognition in Anatomy Educators*, explored the metacognitive practices of educators as they taught in a graduate-level gross anatomy course. Additionally, this study identified the metacognitive foci of the educators (e.g., their teaching practices, student interactions, etc.) through a series of teaching self-reflections. The results from this multiple-methods study provide insight into how educators engage in metacognition as they teach the anatomical sciences as well as inform how to best support the professional development of these educators. Together, these three studies advance what is currently known about metacognition in the context of anatomical sciences education by describing the metacognitive practices of both students and educators.

1.3 Research Questions

To address the gaps in the metacognition literature, this series of studies investigated the metacognitive practices of students and educators involved with the anatomical sciences. The overarching research questions addressed are as follows:

- What aspects of teaching and learning the anatomical sciences do students and educators focus on when engaging in metacognitive reflection?
- How can additional awareness of metacognitive practices in both learners and educators contribute to anatomical sciences education for allied health and medical students?
- Which previously described metacognitive principles, if any, are applicable to students and educators specifically in the anatomical sciences?

Additionally, the research questions for each individual study are as follows:

1. *Metacognition in Allied Health Students*

- What aspects of their learning do allied health students focus on when they engage in metacognitive reflection via online reflective discussion boards?
- How does the metacognitive focus of allied health students change as they progress through a graduate-level anatomy course?
- What are the relationships between student metacognition, assessment performance, and program of study?

2. *Metacognition in First-Year Medical Students*
    - What aspects of their learning do medical students focus on when they engage in metacognitive reflection before and after their first professional-level integrated anatomy exam?
    - How accurate are repeating and non-repeating students when using their metacognitive skills to predict their performance on their first integrated anatomy exam?
    - What relationships are present between the assessment confidence, satisfaction, predicted scores, and actual scores of repeating and non-repeating students?
    - What study strategies and resources do first-year medical students use to prepare for their first integrated anatomy exam, and how do their approaches change in response to their performance?
    - How do the self-described exam preparation strategies and the focus of metacognition differ between repeating and high-performing students?
3. *Metacognition in Anatomy Educators*

- What aspects of their teaching do anatomy educators focus on when they engage in metacognition while teaching in a graduate-level gross anatomy course?
- How does the metacognitive focus of anatomy educators change as they teach in a graduate-level gross anatomy course?
- How does metacognitive focus differ between anatomy educators based on teaching experience?

1.4 Study Design

To answer the aforementioned research questions, these studies employed several multiple methods approaches for data collection and analysis. Quantitative data was primarily collected through online questionnaires that include demographical items and previously validated survey constructs, as well as through assessment data. These data were then analyzed using the appropriate descriptive and inferential statistical methods. Qualitative data were collected through a variety of methods such as asynchronous online discussion boards or reflective assignments. These qualitative data were then analyzed using inductive and/or deductive approaches to thematic or framework analysis. These approaches will be described in more detail in Chapter 3: Methods.

1.5 Dissertation Overview

Chapter 2 begins with a review of the existing metacognition literature, including a brief history of metacognition, an overview of key metacognitive principles, and the metacognition of specific populations such as allied health students, medical students, healthcare professionals, and educators. Chapter 3: Methods will then detail the studies through which the research questions were addressed. Each study description includes participant recruitment, study context, data collection methods, and data analysis methods. The data collection instruments referenced in the Methods section can be found in their entirety in the Appendices. Chapter 4: The Results then describe the quantitative and qualitative findings of the described studies in great detail. Lastly, Chapter 5: Discussion and Conclusions interprets the findings of the studies, both individually and collectively, in the context of the existing metacognition and anatomy education literature.

CHAPTER 2. REVIEW OF THE LITEATURE

2.1 What is Metacognition?

Metacognition was first described by John Flavell in 1976 as “cognition about cognitive phenomena”, or more simply put, “thinking about thinking” (Flavell, 1979). In this seminal study, Flavell asked elementary school children to evaluate the thoroughness of a set of verbal instructions. Despite the inclusion of numerous omissions and inconsistencies, the young children falsely believed the instructions were sufficiently thorough for them to complete the associated task. The children’s misjudgment of their own knowledge led Flavell to conclude that the children were limited in their “cognition about cognitive phenomena, or in their metacognition” (Flavell, 1979).

Flavell’s initial model of metacognition was comprised of four elements: (1) metacognitive knowledge, (2) metacognitive experiences, (3) goals/tasks, and (4) actions/strategies. Metacognitive knowledge consists of the individual’s knowledge of their own cognition. Metacognitive experience refers to the individual’s affective responses that occur during their cognition. Lastly, goals/tasks pertain to the objective of an individual’s cognition, whereas actions/strategies refer to the cognitive methods used to achieve their goals. Flavell anticipated applications for his model of metacognition in both developmental psychology as well as education (Flavell, 1979).

Since Flavell’s first description, several other researchers have investigated metacognition and developed their own definitions, theories, and models of metacognitive thought. Some examples include Ann Brown’s model of “metacomprehension” (Brown, 1977), Borkowsky and Pressley’s good information processing model (Pressley et al., 1989), and Kuhn’s model of meta-knowing (Kuhn, 1999; Tarricone, 2011). Each of these models advanced what was known about metacognition and further refined the categorization of metacognitive elements. For example, Brown's model was the first to organize metacognition into "knowledge of cognition" and "regulation of cognition," which are now widely considered to be two key elements required for full engagement in metacognition (Tarricone, 2011). These various models of metacognition overlap heavily, making them highly compatible with one another.

In the studies, we will explore the metacognition of students and educators in the anatomical sciences using Flavell's revised model of metacognition (Flavell et al., 2002). This model was selected because it builds upon Flavell's seminal work by incorporating other key advances from the metacognition literature. As a result, Flavell's revised model is more comprehensive and assesses metacognition across the three known domains of metacognition: (1) metacognitive knowledge, (2) metacognitive regulation, and (3) metacognitive experience (Table 1) (Flavell et al., 2002). Incorporation and alignment with other metacognitive frameworks make it possible for Flavell's revised model to be used in conjunction with other metacognitive instruments such as Schraw and Dennison's Metacognitive Awareness Inventory (MAI), one of the most widely used tools for assessing metacognition (Schraw and Dennison, 1994).

Table 1. Flavell's Model of Metacognition

	Domain	Sub-domain
Metacognition	**Metacognitive Knowledge (MK)** Knowledge of one's own cognition and awareness of internal or external factors that may impact cognition	**Knowledge of Persons** Knowledge of one's own cognition
		Knowledge of Tasks Knowledge of specific tasks, goals, and conditions
		Knowledge of Strategies Knowledge of potential methods of addressing a specific goal or task
	Metacognitive Regulation (MR) Ability to control one's own learning and cognition	**Planning** Goal setting, strategy selection, prediction, and resource allocation toward a future endeavor
		Monitoring Real-time awareness of learning or performance
		Evaluation Self-assessment of one's learning or performance through reflection
	Metacognitive Experience (ME) Affects experiences that emerge during the performance of a task	• Feelings of familiarity, difficulty, knowing, confidence, satisfaction • Judgments of learning, effort, or time

The first dimension, Metacognitive Knowledge (MK), refers to an individual's knowledge of their own cognitive strengths and weaknesses, including awareness of any internal or external factors that may impact their metacognition (Flavell et al., 2002; Zohar and Barzilai, 2013). In Flavell's revised model, the MK dimension can be further divided into three subdomains: knowledge of (1) persons, (2) tasks, and (3) strategies.

Knowledge of persons relates to an individual's knowledge of factors that can influence their own cognition or the cognition of others (e.g., "I know I typically struggle with learning abstract concepts"). Knowledge of tasks refers to an individual's knowledge of specific tasks, goals, and conditions (e.g., "I need to learn anatomical relationships for the identification questions on the practical exam"). Lastly, knowledge of strategies pertains to an individual's knowledge of potential methods of addressing a specific goal or task (e.g., "I find practice questions to be helpful in self-assessing my knowledge"). According to some metacognition experts, the MK domain is the most critical element because it informs the other domains of metacognition by providing the foundational information needed to regulate metacognition or generate metacognitive experiences (Tarricone, 2011).

The second dimension, Metacognitive Regulation (MR) refers to an individual's ability to monitor, evaluate, and self-regulate their own learning and cognition (Flavell et al., 2002; Zohar and Barzilai, 2013). Under Flavell's model, the domain of MR includes the subdomains of (1) planning, (2) monitoring, and (3) evaluation. Planning involves setting goals, selecting strategies, making predictions, and allocating resources toward a future endeavor (e.g., "I will use flashcards every day to practice recalling all the muscle attachments"). Monitoring refers to real-time awareness of learning or performance (e.g., "I don't think I understand what the instructor just explained"). Evaluation involves assessing the effectiveness or efficiency of one's learning or performance through reflection (e.g., "I missed several questions on autonomics so I need to learn them more thoroughly for the final") (Tarricone, 2011).

Lastly, Metacognitive Experience (ME), the third and least investigated dimension of metacognition focuses on emotions, judgments, or thoughts that emerge during the performance of a task (Flavell et al., 2002; Efklides, 2006). These affective experiences are less analytical in nature compared to MK or MR and can include feelings of knowing, difficulty, familiarity, confidence, satisfaction, or correctness (Efklides, 2006). For example, during a closed-book exam, the examinee may have a "gut-feeling" that one of their answers is incorrect and second guess themselves. Although MEs are not present in all models of metacognition, they still play a significant role. Feelings are a product of self-monitoring during task performance and serve to inform the person about the progress of cognitive processing. Although MEs can occur during any cognitive task, they typically occur when an individual must perform under sub-optimal conditions such as during a closed-book exam or a pop quiz (Efklides, 2006). Although these "gut-feelings" are unintentional and sometimes inaccurate when compared to purposeful metacognitive monitoring, they inform the individual that something may be amiss.

2.2 Assessing Metacognition

As a non-explicit behavior, metacognition cannot be directly observed or assessed. Instead, only the external behaviors that occur as a result of metacognition can be observed and assessed. This obstacle is further complicated by the fact that many individuals are not aware of their engagement in metacognition (Akturk and Sahin, 2011). However, several alternative methods have been developed to indirectly assess metacognition by looking at the subsequent results of metacognition. Overall, the existing methods for assessing metacognition can be organized into two categories: self-report methods (e.g. questionnaires or reflective writing) and systematic observation methods (e.g. eye-tracking and think-aloud protocols) (Akturk and Sahin, 2011). Each category offers their own strengths and weaknesses in capturing an individual's metacognition. The following sections will delve into the different methods of assessing metacognition and their individual strengths and weaknesses.

2.2.1 Survey Instruments

One of the most common methods of evaluating metacognition is through survey instruments that ask participants to self-report their own metacognition (Akturk and Sahin, 2011). When developed in close consultation with metacognition theory and properly evaluated for reliability and validity, survey instruments can provide reasonably accurate assessment of metacognition, especially if combined with additional methods of assessment (Ozturk, 2017). Moreover, surveys can be completed privately or anonymously, which can encourage participants to respond more genuinely than if they were under direct observation (McNeely, 2012). If widely distributed, this method of assessment can also facilitate data collection from a large population with only a small investment of time and effort. Once validated, the survey instrument can also be implemented beyond the original study. However, this method of assessment is limited in its data capture and does not allow for rich, nuanced data collection due to the restrictive, closed-ended survey items. Also, as noted in previous studies, human memory is far from perfectly accurate, meaning that the individual's recall of their thought processes may be significantly altered by the time they complete a self-report survey (Sudman and Bradburn, 1973; Bradburn et al., 1987). Also, some individuals may not be fully aware of when they engage in metacognition or what metacognitive thoughts necessarily entail (Akturk and Sahin, 2011). As a result, their reports of their metacognition may not fully represent their experience at that time.

The most well-known and widely used survey instrument for measuring metacognition is the Metacognitive Awareness Inventory (MAI; Appendix A) developed by Schraw and Dennison (1994). The original version of the survey instrument included 52 dichotomous items, with each item answered on a continuous, 100-point scale. As a result, scores could range between 52 and 5200. Several studies have since modified the MAI's original response and scoring methods into true-false or Likert-style scales (Akin et al., 2007; Abdullah and Soemantri, 2018; Harrison and Vallin, 2018; Dunn et al., 2019; Tatić et al., 2019). Similar to the Flavell's and Brown's models, metacognition is assessed by the MAI across two overarching domains: knowledge of cognition and regulation of cognition. The domain of knowledge of cognition is essentially the MK domain as described above but is further subdivided into three additional subdomains: declarative knowledge, procedural knowledge, and conditional knowledge. Similarly, the regulation of cognition domain is comparable to the MR domain as described above but is subdivided into planning, information management, debugging strategies, evaluation, and comprehension monitoring. Exploratory and confirmatory factor analysis supported the two-factor model of metacognition and determined that the factors were both reliable (α=0.90) and inter-correlated (r=0.54) (Schraw and Dennison, 1994). However, a recent study determined that while the two-factor structure of the MAI is valid, the overall 52-item survey exhibits poor fit. Instead, the results support the use of an abridged, 19-item version of the MAI due to its improved fit (Harrison and Vallin, 2018).

Additional examples of discipline-general and discipline-specific metacognition survey instruments include the Learning and Study Strategies Inventory (LASSI) by Weinstein et al. (1987) and the Metacognitive Awareness Inventory for Surgical Educators (MAISE) by Jung et al. (2022). These referenced surveys represent a small fraction of the vast number of survey instruments available for assessing domain-general and domain-specific metacognition, but they do illustrate the breadth and depth that can be achieved. Each survey instrument includes different survey items tailored to different populations and disciplines, thus providing multiple methods for capturing various aspects of an individual's metacognition. However, no single survey can perfectly capture the entirety of an individual's metacognition.

2.2.2 Reflective Writing

Another method of assessing self-reported metacognition is through reflective writing. This approach involves asking the participant to provide written responses to open-ended metacognitive prompts at various intervals of time. Similar to survey instruments, reflective writing can be completed privately and anonymously, increasing the likelihood of the participants responding more honestly. Unlike survey instruments though, reflective writing is conducive to collecting incredibly rich, nuanced data that are unique to each individual (Carr, 1994). Moreover, reflective writing can take many forms, including periodic reflective journals or online discussion boards, which can provide educators with multiple options for incorporating them into their classrooms.

Low-stakes reflective writing assignments can provide students with an avenue to analyze their past and present performances and plan their future approaches, leading to a greater awareness of themselves as learners (Tanner, 2012). After participating in regular online blog entries focusing on patient cases and self-evaluation, upper-level undergraduate anatomy students demonstrated improved self-confidence, enthusiasm, self-assessment of skills, and felt more at ease in the course (O'Loughlin and Griffith, 2020). Another study found that semi-structured journal prompts encouraged deeper student reflections regarding their awareness, evaluation, and regulation of learning as well as more instances of relating the course content to their professional development (Alt and Raichel, 2020). In a study by Trujillo et al., reflective writing assignments based around the MACH model ("Methods, Analogies, Context, and How") also helped undergraduate biology students both explain complex biological mechanisms and identify gaps in their knowledge (Trujillo et al., 2016). Moreover, structured post-assessment assignments that asked students to reflect on their study strategies and build a study plan for future assessments were also shown to engage students in metacognition and guide their study practices (Stanton et al., 2019; Stanton et al. 2021). Post-assessment assignments that required undergraduate biology students to correct and explain their own assessment errors also encouraged the development of metacognitive skills (Mynlieff et al., 2014).

Asynchronous online discussion boards are another form of reflective writing of particular interest, especially with the increased usage of online and hybrid learning, particularly secondary to impacts on education due to the COVID-19 pandemic (Bickle and Rucker, 2020). Similar to the reflective writing exercises described above, studies have found that reflective writing performed via weekly online discussion boards promoted the development of students' metacognitive skills (Snyder and Dringus, 2014).

Furthermore, the social and informal nature of online discussion boards allows students to interact with their peers, which encourages collaboration and the co-creation of knowledge (Giacumo and Savenye, 2020). However, other studies have found that while reflective discussion boards may enhance metacognition, they ultimately have little to no effect on academic performance (Cavilla, 2017). As such, the impact of asynchronous reflective discussion boards on metacognition and academic performance remains inconclusive and requires further investigation.

2.2.3 Systematic Observation

Lastly, systematic observation methods involve measuring the actions that result from metacognition as they occur in real-time as a proxy for metacognition itself (Akturk and Sahin, 2011). Since the measurements occur almost simultaneously with the participant's metacognition, there is a lower likelihood that the participant may inaccurately recall their metacognitive thoughts at a later time (Sudman and Bradburn, 1973; Bradburn et al., 1987). While systematic observation methods allow for more immediate, accurate assessment of the actions that occur as a result of an individual's metacognition, they require a significant investment of time, energy, and resources by both the researcher and the participant (Akturk and Sahin, 2011).

Two of the most common methods of systematic observation of metacognition are think-aloud protocols and eye-tracking. Think-aloud protocols aim to capture the participant's metacognition by having them verbalize their internal dialogue as they perform a specific task to allow researchers to more easily capture the self-talk that accompanies the participant's metacognition in the moment (Benton, 2013). Similarly, eye tracking studies aim to capture an individual's metacognition by directly observing their eye movements as they complete a specific task. As the individual engages in a specific task, their gaze patterns or fixation behaviors can indicate areas of interest, and thus provide insight into the individual's thought processes (Zumwalt et al., 2015).

To address the research questions, the studies described in this dissertation primarily relied on self-report methods of assessing metacognition, specifically survey instruments and reflective writing activities. Although systematic observation methods may allow for more accurate, real-time assessment of metacognition, they require a significant investment of time, energy, and resources to perform properly. Given the large population of potential participants (allied health students, medical students, and educators) and the limited number of researchers for data collection and analysis, self-report methods were more feasible under these circumstances. Self-report methods allowed for data collection from large and diverse populations simultaneously, thereby avoiding the omission of any key participants from the studies. All survey instruments used in the studies (e.g., the MAI and TMI) were also selected for their close adherence to the metacognition literature and have been deemed valid and reliable by previous studies (see Sections 3.1.3, 3.2.4, and 3.3.3). The MAI was selected for implementation in the first study due to its extensive usage and validation across multiple educational contexts and populations. The structure of the MAI is also closely aligned with that of Flavell's revised model of metacognition, thereby facilitating data analysis and interpretation. For the second study, the Practice-Based Learning and Improvement (PBLI) was selected due to its basis in the metacognition literature. Similarly, the TMI was also selected for use in the third study due to its close alignment with Flavell's revised model and inclusion of all three dimensions of metacognition. The reflective writing activities (e.g., online discussion boards and reflective journals) will also be grounded in the metacognition literature (Schraw and Dennison, 1994; Tanner, 2012; Jiang et al., 2016). Epistemologically, using both these quantitative and qualitative self-report methods will allow for accurate capture of what the participants perceive to be their truth regarding their metacognition. In the future, subsequent studies may employ systematic observation methods to explore metacognition in a limited number of participants.

2.3 Metacognition in Students

2.3.1 Higher Education Students in General

In the context of higher education, metacognition can improve the ability of students to think critically (Naimnule and Corebima, 2018), evaluate their strengths and weaknesses as learners, and identify the appropriate learning strategies to achieve their goals (Stanton et al., 2019). In the case of undergraduate animal physiology students, metacognitive skills were determined to be strongly correlated with critical thinking skills (Amin et al., 2020). Additionally, undergraduate engineering students who consistently engaged in metacognitive reflection were found to perform better on assessments, projects, and homework assignments when compared to their less reflective peers (Menekse et al., 2022). Ultimately, this self-awareness leads to improved academic performance, increased ownership of learning, and more positive and growth-oriented attitudes towards learning (Cho et al., 2017; Lazendic-Galloway et al., 2019).

Due to the COVID-19 pandemic, the education landscape has profoundly changed, and anatomy education was not spared from such impacts. Changes in anatomy education as a result of the COVID-19 pandemic include a decrease in cadaveric dissection and increase in digital materials (Attardi et al., 2021; Harmon et al., 2021) and resulting impacts on students' learning (Pather et al., 2020; Owolabi and Bekele, 2021). The COVID-19 pandemic has also thrown students into learning situations in which they were forced to reflect internally on their own learning and rely on their metacognitive skills, as they were unable to converse with instructors as easily as they had done pre-pandemic (Anthonysamy, 2021). Therefore, identifying and improving (if necessary) metacognitive skills among students is increasingly important, particularly in coursework that was and continues to be impacted by pandemic-related teaching practices.

2.3.2 Allied Health Students

Allied health students focusing on physical therapy, occupational therapy, and physician assistant studies can also benefit significantly from improved metacognitive skills. Although the accrediting bodies for allied health programs do not include metacognitive skills in their curricula standards, many medical educators and practicing allied health professionals advocate for their inclusion in allied health education (ACOTE, 2018; CAPTE, 2022). These groups argue that as future healthcare professionals, allied health students need the ability to monitor and self-regulate their own learning and clinical performance (Prokop 2018).

Multiple studies have demonstrated the significance of metacognition to allied health education (Naug et al., 2011; Tan et al., 2010; Honeycutt et al., 2021).

Engagement in written metacognitive reflection encouraged deeper learning in allied health students, particularly in problem-solving, critical thinking, and troubleshooting complex clinical errors (Honeycutt et al., 2021). Similarly, periodic blogging on clinical practice promoted metacognition and improved clinical reasoning in undergraduate physiotherapy students (Tan et al., 2010). Allied health students in a gross anatomy course also performed better on assessments after engaging in a metacognitive "blank page" challenge that required them to recall information and identify gaps in their own knowledge (Naug et al., 2011; Naug et al., 2016). The first study in this dissertation contributes to the literature by determining how the metacognition of allied health students changes over a semester of gross anatomy.

2.3.3 Undergraduate Medical Students

Metacognition is also recognized as an essential skill for medical students in both academic and clinical settings. In the United States, the Liaison Committee on Medical Education (LCME) has included metacognitive skills in the standards for medical school accreditation to ensure their development in all students (Standard 6.3) (LCME, 2022). Medical school curricula must include self-directed learning experiences that involve "self-assessment of learning needs; independent identification, analysis, and synthesis of relevant information; appraisal of the credibility of information sources; and feedback on these skills from faculty and/or staff" (LCME, 2022). Interestingly, some students may not agree, instead viewing their medical education as an exercise in rote memorization (Versteeg et al., 2021).

Several studies have linked metacognitive skills to improved educational outcomes in undergraduate medical education (Gardner et al., 2016; Hill et al., 2020; Siqueira et al., 2020; Chang, 2021; Martin-Piedra et al., 2022). For example, medical students with greater metacognitive awareness have been shown to be more adept at identifying threshold concepts that are key to understanding a topic (Martin-Piedra et al., 2022) as well as more motivated to learn independently, leading to autonomous self-regulated learning (Hill et al., 2020; Siqueira et al., 2020). An increase in students' metacognitive skills has also been linked to improved performance on standardized progress assessments (Chang, 2021). Beyond the academic setting, metacognition can also aid in the development of clinical skills as well. Since medical clerkships are grounded in experiential learning, student learning is dependent on critical self-reflection and accurate self-assessment (Cho et al., 2017). Medical students who were provided with learning goals to metacognitively plan around were more proficient at surgical suturing and knot-tying compared to their peers (Gardner et al., 2016). Medical students who were trained to engage in metacognition during clinical decision-making using a mnemonic checklist performed significantly better than their peers in a series of clinical scenarios (Chew et al. 2016). Metacognitive reflection on pathophysiology, complications, and treatments after engaging in patient encounters also helped improve students' skills at generating medically-appropriate prescriptions (Hennrikus et al., 2018).

Currently, the literature is unclear on how the metacognition of medical students changes through the different stages of their medical education. As described, a plethora of studies have found that student metacognition can be improved through a variety of educational interventions and benefits their medical education significantly. However, first-year medical students have been found to lose self-efficacy and preferentially use surface learning strategies over deep learning strategies despite the introduction of metacognitive activities (Papinczak et al., 2006). Another study found that students transitioning between the didactic and clinical phases of their education experienced a marked decrease in their metacognition, particularly in students who had previous clinical experience (Stansfield et al., 2015; Cho et al. 2017). The second study contributes to this existing discussion on metacognitive change by determining if a change occurs during the first semester of medical school as well as how this change occurs in student populations with varying academic performance.

2.4 Metacognition in Healthcare Professionals

Once medical and allied health students transition into their roles as healthcare providers, metacognitive awareness becomes even more crucial. Medical science is constantly advancing, often at a rapid pace. In an address to graduating medical students, Dr. David Sackett, widely considered as the "father of evidence-based medicine", even cautioned that "Half of what you'll learn at medical school will be shown to be either wrong or out of date within five years of graduation; the trouble is that nobody can tell you which half, so the important thing to learn is how to learn on your own" (Smith et al., 2019, pg. 1430). Well-developed metacognitive skills can help healthcare professionals adapt to these unpredictable changes more readily. Metacognitive skills play such a critical role for healthcare professionals that they are often incorporated into the standardized learning outcomes for trainees (Colbert et al., 2015). In the United Kingdom, "all physicians are expected to reflect on their own performance" whereas

Canadian resident physicians are expected to “demonstrate insight into their own limitations of expertise via self-assessment” (Frank, 2005; Archer and Regan de Bere, 2013). Resident physicians in the United States must also learn to “self-assess and use self-directed learning skills to improve patient care” as part of their training (Colbert et al., 2015).

Previous studies have linked the development of metacognitive skills with improved patient safety, clinical reasoning, and clinical decision-making as well as reduced diagnostic errors among nurses, physicians, and physicians-in-training (Kuiper and Pesut, 2004; Royce et al., 2019; Siqueira et al., 2020). For example, when presented with complex clinical scenarios, experienced clinicians consistently relied on their metacognitive skills to identify relevant details and adapt their basic science knowledge into an appropriate clinical decision whereas novices relied more heavily on predetermined treatment routines (Byrne, 2013). Metacognitive clinicians were also more adept at identifying and avoiding cognitive biases that often lead to diagnostic errors in their clinical decision making (Royce et al., 2019). Additionally, obstetricians who were more metacognitive were also linked with improved outcomes for patients undergoing complex deliveries such as vaginal birth after a prior cesarean (Yee et al., 2015). Conversely, a lack of metacognitive skills can lead to an overestimation of abilities or reduced self-monitoring and thus, medical errors (Medina et al., 2017, Royce et al., 2019). According to a study by Moulton et al., surgeons attributed surgical errors to a failure to maintain metacognitive self-monitoring throughout the surgical procedure (2010). Ultimately, these lifelong learning skills can help healthcare providers maintain a high standard of patient care throughout their careers as medicine evolves; therefore, it is important that these skills be taught early in healthcare professionals' education.

2.5 Metacognition in Educators

Although most metacognition research focuses on students, significant evidence suggests that improved metacognition can benefit educators as well (Wilson et al., 2010.; Vrieling et al., 2012; Noormohammadi 2014; Ali and Yasmeen, 2019). Interestingly, many educators are unfamiliar with the concept or reluctant to integrate it into their curricula (Ben-David and Orion, 2003). However, after being introduced to and trained in metacognitive principles, some educators were amazed at how such an important and relevant concept was overlooked in their training and expressed great interest in developing their knowledge of metacognition to incorporate into their curricula (Ben-David and Orion, 2003). Educators with a greater understanding of metacognitive principles are more proficient at translating their skills into teaching strategies that also engage their students in metacognition (Wilson et al., 2010) and more motivated as educators (Vrieling et al., 2012). Metacognitive monitoring can also help educators gauge the progress of their students in real-time and guide their strategies for future teaching sessions (Ali and Yasmeen, 2019). Additionally, metacognitive activities can help novice teachers gain a better understanding of prior knowledge and how it can be leveraged in constructivist teaching (Meyer 2006). Moreover, improved metacognition is positively correlated with teacher self-efficacy and teacher autonomy (Noormohammadi 2014).

However, most of the existing research on educator metacognition was performed with pre-service, primary, or secondary school educators. This gap may be caused by barriers to participation in the scholarship of teaching and learning for many post-secondary educators such as lack of pedagogical knowledge or institutional and departmental politics (Cotton et al., 2018). Unlike most post-secondary educators, primary and secondary educators undergo mandatory training in pedagogical techniques, curriculum development, and classroom management as part of their teaching certification (Indiana Department of Education, n.d.). Furthermore, discipline-specific, post-secondary-educators often deliver instruction through techniques that are more specialized to their disciplines (e.g., one-on one human cadaveric dissection or small-group case-based learning) (Middendorf and Pace, 2004; Coppola and Krajcik, 2013). As such, the findings of these studies may not be applicable to discipline-specific educators such as anatomical sciences educators. Few studies have investigated the metacognition of anatomical sciences educators and other discipline-specific educators in post-secondary or professional education. To my knowledge at the time of writing, my study is the first to explore metacognition in anatomical sciences educators, specifically. The insights gained from the proposed studies will expand what is currently known about the metacognition of anatomical sciences educators teaching in their unique educational circumstances.

In teacher education, metacognition is commonly practiced through various forms of written or verbal reflection in which the educator reflects on their past teaching sessions. For example, in a study by Baird et al. which engaged pre- and in-service science teachers in individual and collaborative group reflection, both educator groups felt encouraged to further their professional development as educators, particularly in their knowledge, awareness, and control of themselves and their classrooms (Baird et al., 1991). Metacognitive reflection also helps alter preconceived conceptions about teaching such as teaching being an innate skill, leading to teaching strategies that are more learner-centered than teacher-centered (Ebert-May et al., 2017; Rao et al., 2017). Although many educator training programs view metacognitive reflection as an essential skill (Gunstone et al., 1993, Ebert-May et al., 2017; Rao et al., 2017), some experts argue that reflection does not directly improve teacher or student performance and may even be harmful due to poor execution. These opponents argue that while reflection is necessary and should be encouraged, the practitioners rarely translate their reflections into real action (Beauchamp, 2015), thereby wasting their time and energy without added benefit. Other critiques include lack of genuine reflection, narrowness of approaches to reflection, problematic ethical considerations, and structural limitations on reflection (Beauchamp, 2015). However, these critiques are slowly being addressed by implementing programs that make a stronger connection between metacognitive theory and practice, resulting in educators who are more comfortable with and likely to apply theory to their teaching (Stenberg et al., 2016). The third study adds to the literature on educator metacognition by determining if educators can benefit from metacognitive reflection via journaling as well as how various educator populations engage in metacognition.

2.6 Chapter Summary

In summary, metacognition, the ability to critically think about one's own thinking, is a powerful skill that can enhance learning and performance. The primary components of metacognition include (1) metacognitive knowledge, (2) metacognitive regulation, and (3) metacognitive experience. Since its initial description in the context of developmental psychology, metacognition and its components have been investigated in a variety of disciplines and populations, including higher education, allied health students, medical students, clinicians, and educators. As a non-explicit behavior, an individual's metacognition cannot be directly assessed, though several indirect assessments methods have been developed such as survey instruments, reflective writing activities, and systematic observation protocols. The next section of this dissertation, Chapter 3: Methods, will describe how some of these indirect assessment methods were used to explore and assess the metacognitive practices of allied health students, first-year medical students, and educators in the context of anatomical sciences education.

CHAPTER 3. METHODS

3.1 Metacognition in Allied Health Students

3.1.1 Study Overview and Participants

This study was designed to address the following study-specific research questions: (1) what aspects of their learning do allied health students focus on when they engage in metacognitive reflection via online reflective discussion boards, (2) how does the metacognitive focus of allied health students change as they progress through a graduate-level anatomy course, and (3) what are the relationships between student metacognition and assessment performance and program of study? First-year students in the Doctor of Physical Therapy (DPT; n=45), Masters of Physician Assistant Studies (MPAS; n=46), and Doctor of Occupational Therapy (OTD; n=38) programs within the Indiana University School of Health and Human Sciences during the summer of 2020 were invited to participate in this study. As part of their first-year curricula, students participated in an interprofessional anatomy course, “Anatomy for Healthcare Professionals”. Enrolled students were invited to complete a metacognition awareness questionnaire prior to and towards the end of the course and were asked to participate in discussion topics throughout the course related to metacognition and professional development.

3.1.2 Study Context: ANAT D528 Anatomy for Healthcare Professionals

Anatomy for Healthcare Professionals (D528) is a 5-credit hour, graduate-level anatomy course designed to introduce allied health students to the basic concepts and structures of the human body. The concurrent course load of each program varies from no additional courses for DPT students, to three additional credit hours for OTD students, and 13 additional credit hours for MPAS students.

D528 follows a regional approach and is divided into four blocks culminating in summative assessments in the following regions: (1) Back and Upper Limb, (2) Thorax and Abdomen, (3) Pelvis and Lower Limb, and (4) Head and Neck. All lectures are pre-recorded and delivered asynchronously through the institution's learning management system (Canvas LMS; Thoma Bravo LLC; Chicago, IL). For laboratory sessions, students are assigned to interprofessional laboratory groups (n=6 students/group) with approximately two students from each program in a group (i.e., PT, OT, and PA). Meanwhile, instructors (faculty, Ph.D. students, and teaching assistants) visit each table to answer questions and provide dissection assistance.

Due to the COVID-19 pandemic, all course components of the 2020 iteration were delivered virtually. Virtual laboratory sessions were conducted synchronously using Zoom (Zoom Video Communications, Inc., San Jose, CA). During the laboratory sessions, each group was placed in their own breakout room and completed a worksheet of short answer and identification questions on illustrations, radiographs, and cadaveric images to reinforce concepts encountered in lecture. Assessments were conducted online using Examplify (ExamSoft Worldwide, Inc., Dallas, TX), which included 85 multiple-choice questions, 60 of which were higher-order and clinically-relevant questions; the remaining 25 questions were first order "tag"-style (i.e. "identify") on cadaveric images in a multiple-choice format (with "none of the above" always available as an answer). During the synchronous laboratory sessions, students voluntarily responded to Likert questions using TopHat (TopHatMonocle, Corp., Toronto, Ontario), an audience response system. Prior to each session, metacognitive survey questions were shared with students alongside formative practice questions pertaining to the recent material. The topics of the metacognitive questions included anticipated exam grades (1=poor performance, 5=strong performance), satisfaction with exam grades (1=low satisfaction, 5=high satisfaction), interest in block material (1=not interested, 3=interested), engagement in comprehension monitoring (1=no, 2=yes), and anatomy content difficulty (1=not difficult, 3=difficult).

To encourage the development of metacognitive awareness and skills among the students, a series of voluntary discussion prompts were also deployed on Canvas (Appendix B). New discussion prompts were posted each week to encourage students to regularly practice engaging in metacognition and reflect on specific aspects of their learning. Discussion topics were developed using the existing metacognition literature and included post-assessment self-reflections, evaluation of study strategies, and monitoring of learning. To prevent students from influencing each other's responses, all responses were hidden until a student had posted their own response. At which point, existing responses from peers and instructors were revealed to allow students to engage in the conversation. Participation was encouraged by informing students that the discussion boards were regularly monitored by teaching staff and any responses or questions would be replied to in a timely manner.

3.1.3 Research Questionnaires

Pre- and post-metacognition questionnaires were hosted online through Qualtrics (Qualtrics, LLC., Drive Provo, UT). At the start of the D528 course, students were invited to complete the pre-questionnaire, which included a demographics section which included current age, gender, program of study, and highest earned degree and a modified Metacognitive Awareness Inventory (MAI; Appendix A). As previously described in Section 2.2.1, such surveys allow for reasonably accurate assessment of participant metacognition and easily distributed to a large population for data collection. The MAI, developed by Schraw and Dennison, is a 52-item questionnaire that assess metacognition across eight different categories: declarative knowledge, procedural knowledge, descriptive knowledge, planning, debugging strategies, comprehension monitoring, information management strategies, and evaluation (1994) (Table 2). The MAI was specifically selected for this study due to its extensive usage across multiple educational contexts and populations. The structure of the MAI also parallels the structure of Flavell's revised model of metacognition, thereby facilitating data analysis and interpretation. Additionally, the MAI has been extensively validated using factor analysis across multiple populations, including in medical education (Cronbach's alpha = 0.904) (Akin et al., 2007; Abdullah and Soemantri, 2018; Harrison and Vallin, 2018). The MAI was modified from its original 100-point slider or five-point Likert scale format to true-false answering in an effort to reduce student survey fatigue, a modification for which there are multiple precedents (Othman and Abdullah, 2018; Dunn et al., 2019; Tatić et al., 2019). Metacognitive Awareness Inventory (MAI) scores and subscores were calculated by providing one point for each "true" response and zero points for each "false" response, with 52 being the maximum possible total score. This modified version had an acceptable level of internal consistency, as determined by a Cronbach's alpha of 0.7 (Taber, 2018). Based on our own calculations, the two primary domains of the survey, knowledge of cognition and regulation of cognition, also had acceptable levels of internal consistency, with Cronbach's alphas of 0.7 and 0.8, respectively. After students completed the questionnaire, their personal MAI results and the interpretation of each score and subcategory was shared with the students in an effort to inform them of their metacognitive strengths and weaknesses and give them time to make the appropriate modifications. Students were encouraged to contact an instructor with questions or concerns regarding their MAI results.

Table 2. Summary of Metacognitive Awareness Inventory (MAI) Domains

Category	Description
Declarative Knowledge	The factual knowledge the learner needs before being able to process or use critical thinking related to the topic
Procedural Knowledge	The application of knowledge for the purposes of completing a procedure or process
Conditional Knowledge	The determination under what circumstances specific processes or skills should transfer
Planning	Planning, goal setting, and allocating resources *prior* to learning
Information Management Strategies	Skills and strategy sequences used to process information more efficiently (e.g., organizing, elaborating, summarizing, selective focusing)
Comprehension Monitoring	Assessment of one's learning or strategy use
Debugging Strategies	Strategies to correct comprehension and performance errors
Evaluation	Analysis of performance and strategy effectiveness after a learning episode

The post-questionnaire was administered one week prior to the end of the D528 course. This questionnaire collected student perceptions regarding the metacognitive discussion boards using Likert-scale and open-ended items and once again asked students to complete the modified MAI. Students were provided with their MAI scores once again after they completed the post-questionnaire in an effort to support their continued metacognitive growth. Pre- and post- questionnaire responses were linked to a single individual for analysis using a unique user-generated identification code, however all data were then de-identified.

3.1.4 Statistical Analysis

All quantitative data were exported from their original platforms and imported into SPSS analysis software (v.27, IMB Inc., Armonk, NY). Descriptive statistics were calculated and data were tested for normality. Spearman's rho analyses were used to identify any significant correlations between numeric variables. Pre- and post-course MAI scores were compared using Related-Samples Wilcoxon Signed Rank Test. Differences in individual block exam performance, MAI scores, discussion board response frequency, and TopHat Likert responses across the three programs of study were identified with Kruskal Wallis H Tests. Furthermore, all students were divided into three performance terciles based on their average exam performance on each exam. The MAI scores, anticipated exam grade, actual exam grade, and exam satisfaction were then compared across the terciles using Kruskal Wallis H Test. Results for all statistical analyses were considered significant if $p<0.05$.

3.1.5 Qualitative Analysis

Discussion board responses were exported, collated, deidentified, and imported into Dedoose qualitative analysis software (SocioCultural Research Consultants, LLC, Manhattan Beach, CA). Qualitative analysis was performed using Braun and Clarke's method of thematic analysis (Braun and Clarke, 2006, 2013; Clarke et al., 2015; Braun et al., 2022). This method of thematic analysis involves six primary phases in an iterative process: (1) familiarization, (2) coding, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) reporting. First, one researcher (A.S.C.) reviewed all discussion board responses to develop familiarity with items of interest related to the research questions. Following familiarization, that researcher identified provisional codes inductively, allowing the data to drive the coding process from the bottom up. To evaluate initial coding reliability, a second researcher (M.A.M.) reviewed the initial coding. Following this review of the provisional codes, codes were reviewed in successive meetings until consensus was reached (100% agreement) and a final codebook was agreed upon. The codebook will then be applied to all discussion responses. After the coding process, codes were organized into provisional themes based on their relationships to one another. Lastly, the provisional themes were reviewed, defined, and named by two researchers (A.S.C. and M.A.M).

Table 3. Overview of Study #1 Research Methods

Research Question	Data Collection	Data Analysis
(RQ1) What aspects of their learning do allied health students focus on when they engage in metacognitive reflection via online reflective discussion boards?	• Metacognitive discussion boards	• Thematic analysis (inductive)
(RQ2) How does the metacognitive focus of allied health students change as they progress through a graduate-level anatomy course?	• Metacognitive discussion boards	• Thematic analysis (inductive), with focus on comparing responses at various timepoints
(RQ3) What are the relationships between student metacognition and assessment performance and program of study?	• Metacognitive Awareness Inventory (MAI) • Metacognitive TopHat questions • Exam scores	• Kruskal Wallis H Test • Related samples Wilcoxon signed rank test • Spearman's rho test

3.2 Metacognition in First-Year Undergraduate Medical Students

3.2.1 Study Overview and Participants

The study-specific research questions to be addressed in this study include: (1) what aspects of their learning do medical students focus on when they engage in metacognitive reflection before and after their first professional-level integrated anatomy exam, (2) how accurate are repeating and non-repeating students when using their metacognitive skills to predict their performance on their first integrated anatomy exam, (3) what relationships are present between the assessment confidence, satisfaction, predicted scores, and actual scores of repeating and non-repeating students, (4) what study strategies and resources do first-year medical students use to prepare for their first integrated anatomy exam, and how do their approaches change in response to their performance, and (5) how do the self-described exam preparation strategies and the focus of metacognition differ between repeating and non-repeating students? Five cohorts of first-year undergraduate medical students at all nine campuses of Indiana University School of Medicine (IUSM) between 2016 and 2020 were included in this retrospective study (n=1802). As part of their first-year curriculum, students were enrolled in an integrated anatomy course, Human Structure, and completed a series of self-directed learning assignments, which were reviewed and analyzed for this study. From the five cohorts of medical students, a total of 51 students (2.8%) failed two or more of their first-year courses and were required to repeat their first year, including Human Structure, in its entirety, including all class sessions, assignments, and assessments (see below for criteria for course failure).

3.2.2 Study Context: First-Year Undergraduate Medical Curriculum

At IUSM, the first year of the undergraduate medical curriculum spans ten months (August to May) and consists of eight separate courses: two year-long courses and six semester-based courses. At the beginning of the semester, students take an introductory course in which they begin to develop knowledge, skills, and attitudes befitting novice health care professionals ("Transitions I"). Other courses in the first year are basic science-focused, related to: 1) anatomy, embryology, and histology ("Human Structure; see below for a more detailed description), 2) molecular, cell, and tissue biology, 3) pathophysiological and pharmacological principles of disease states, 4) immunology and infectious organism pathology and 5) brain and nervous system. While these five basic science courses occur, students are concurrently enrolled in two year-long courses focused on clinical skills.

If a student fails to achieve a passing grade in one course, they have the option to repeat an equivalent course during the summer semester or repeat the original course the following year. However, if a student fails two or more of these first-year courses, they are required to repeat the entire first-year curriculum the following year, including all class sessions, assignments, and examinations.

3.2.3 Course Description: MEDX 620 Human Structure

"Human Structure" (HS) is an 8-credit hour, integrated anatomy course designed to introduce first-year undergraduate medical students to the basic gross anatomical, histological, and embryological concepts and structures of the human body. Each fall semester, HS occurs concurrently across all nine campuses of IUSM with standardized course content and activities. Since 2016, several curricular changes have been made to the course, most notably during the COVID-19 pandemic. However, the core structure and content of the course has remained consistent.

Summative assessments include four block examinations in 2016-2019, which was reduced to three in 2020 to accommodate a change in scheduling due to the COVID-19 pandemic, and one final cumulative examination. Each of the block examinations consist of three parts: (1) a written section with 80 multiple-choice questions written in the National Board of Medical Examiners (NBME) style, (2) an imaging section with 40 radiology and histology image questions, and (3) a "tag"-style laboratory practical with 40 fill-in-the-blank style questions. The final cumulative assessment includes a 150-

question, customized NBME examination administered through the official NBME portal. From 2016-2019, students who scored more than two standard deviations below the class mean were considered to have failed the course. In 2020, the grading structure was modified to better accommodate the curricular changes that were implemented during the COVID-19 pandemic. The passing cutoff was set at 67% for the overall course and 62% on the customized NBME final. Although the grading structure changed, there weren't any notable changes in the number of students who passed or failed the course.

If a student only fails HS, they have the option to remediate by completing an equivalent course during the summer semester or repeating HS the following year. If they fail both HS and another first-year course, they are required to repeat the first-year curriculum in its entirety the following year. In the meantime, repeating students must meet with the Student Promotions Committee to reflect on their performance and determine an appropriate plan for improvement.

3.2.4 Practice-Based Learning and Improvement Assignments

To fulfill the self-directed and life-long learning standard set forth by the LCME for medical school accreditation, students are required to complete a two-part Practice-Based Learning and Improvement assignments (PBLIs; Appendix C), prior to and following the first Human Structure exam (Hoffman and Schaefer, 2021). The pre-exam PBLI is administered to students roughly a week prior to their first exam and includes open-ended (n=4) and close-ended questions (n=3) that ask students to reflect on their preparation for the exam, including their strongest and weakest topics, how they identified and addressed their learning needs, most and least helpful resources, confidence, predicted examination scores, and perceptions of how the dissection process has impacted their learning. Two weeks after the first exam scores are released, students must complete the post-exam PBLI, which consists of open-ended (n=2) and close-ended (n=1) questions pertaining to the students' satisfaction with their scores as well as any adjustments they planned to make to their study approaches and resources.

To streamline data management, all submitted PBLIs were exported from the learning management system platform and imported into REDCap (Research Electronic Data Capture), a secure, web-based software platform designed to support data capture and management for research studies.

Table 4. Scoring of Quantitative PBLI Items

	Scoring				
	1	**2**	**3**	**4**	**5**
Pre-Exam PBLI					
Confidence	Not at all Confident	Low Confidence	Moderate Confidence	High Confidence	Certain
Expected Score	<70%	71-84%	85-91%	>92%	
Post-Exam PBLI					
Satisfaction	No	Not Sure	Yes		
Actual Exam Score	Fail (<70%)	Pass (71-84%)	High Pass (85-91%)	Honors (>92%)	

3.2.5 Statistical Analysis

All quantitative data were exported from REDCap and imported into SPSS analysis software (v.27, IMB Inc., Armonk, NY) for statistical analysis. Quantitative PBLI items were scored using the schema shown in Table 4. Descriptive statistics were then calculated, and data were tested for normality. For the purposes of quantitative analysis, students were separated into four tiers based on their performance on the first

Human Structure exam. “Honors” students scored above 92%, “High Pass” students scored between 85-91%, “Low Pass” students scored between 70-84%, and “Fail” students scored below 70%. Although a student falls into the “Fail” tier, they may have recovered enough on subsequent examinations to pass the course. Data pertaining to repeating students’ initial (first) and repeat (second) attempts were separated from the complete dataset for analysis and comparison against non-repeating students. For both the repeater and the non-repeater data subsets, Spearman’s Rho was used to identify any significant correlations between the students’ actual scores, predicted scores, confidence, and satisfaction within a single attempt at the course and across their two attempts. Linear regression was also used to determine the predictive ability of non-repeating students to anticipate their exam performance. Related-Samples Wilcoxon Signed Rank test was then used to compare the students’ actual scores, predicted scores, confidence, and satisfaction from their unsuccessful attempt against those of their repeating attempt. Kruskal-Wallis H test was also used to compare the actual scores, predicted scores, confidence, and satisfaction of the repeating students against those of the non-repeating students. Additionally, a subset of “top performing” students, defined as the students with the highest 3% of scores on the first examination (n=61), were isolated from the data subset and compared against that of the repeating students using Kruskal-Wallis H test. The top 3% of students was selected in an effort to match the population of repeating students, which represented 2.8% of the total medical student population. Results for all statistical analyses were considered significant if $p<0.05$.

3.2.6 Qualitative Analysis

For the repeating students, open-ended PBLI responses from their initial, unsuccessful attempt were qualitatively analyzed in aggregate using the framework analysis method (Gale et al., 2013), a rigorous form of thematic analysis. Framework analysis consists of seven steps: (1) Transcription, (2) Data Familiarization, (3) Coding, (4) Developing an Analytical Framework, (5) Applying the Analytical Framework, (6) Charting Data into Framework Matrix, and (7) Interpreting the Data. Initially, open-ended PBLI responses were transcribed verbatim from REDCap into Dedoose for analysis (Step 1). Next, each of the three researchers (A.S.C., M.A.M., and L.A.H.) individually familiarized themselves with the same subset of responses from the repeating students (n=8) (Step 2). Afterwards, each researcher independently coded that same subset using an inductive approach (Step 3). The researchers then reconvened to discuss code applications and create an analytical framework and a single unified codebook. Each researcher then used the unified codebook to each code differing sets of responses (n=8). Any new codes were discussed and added to the unified codebook (Step 4). A single researcher (A.S.C) then used the unified codebook to code all remaining open-ended responses from the repeating students (Step 5), charted the coded responses into a framework matrix (Step 6) and interpreted the data, organizing it into distinct themes (Step 7). For the top performing students, open-ended PBLI responses from the top 3% of students were isolated and coded using the unified codebook and analyzed using the same framework analysis method in aggregate.

Table 5. Overview of Study Methods (Study #2)

Research Question	Data Collection	Data Analysis
(RQ1) What aspects of their learning do medical students focus on when they engage in metacognitive reflection before and after their first professional-level integrated anatomy exam?	• Practice-Based Learning and Improvement (PBLI) assignments (open-ended items)	• Framework analysis (inductive)
(RQ2) How accurate are repeating and non-repeating students when using their metacognitive skills to predict their performance on their first integrated anatomy exam?	• Practice-Based Learning and Improvement (PBLI) assignments (closed-ended items) • Exam scores	• Kruskal Wallis H test • Related samples Wilcoxon signed rank test • Linear regression
(RQ3) What relationships are present between the assessment confidence, satisfaction, predicted scores, and actual scores of repeating and non-repeating students?	• Practice-Based Learning and Improvement (PBLI) assignments (closed-ended items) • Exam scores	• Spearman's rho test • Kruskal Wallis H test
(RQ4) What study strategies and resources do first-year medical students use to prepare for their first integrated anatomy exam, and how do their approaches change in response to their performance?	• Practice-Based Learning and Improvement (PBLI) assignments (open-ended items)	• Framework analysis (inductive), with focus on comparing pre- and post-exam responses
(RQ5) How do the self-described exam preparation strategies and the focus of metacognition differ between repeating and non-repeating students?	• Practice-Based Learning and Improvement (PBLI) assignments (open-ended items)	• Framework analysis (inductive), with focus on comparing repeating and non-repeating student responses

3.3 Metacognition in Anatomy Educators

3.3.1 Study Overview and Participants

This study was designed to address the following study-specific research questions: (1) what aspects of their teaching do anatomy educators focus on when they engage in metacognition while teaching in a graduate-level gross anatomy course, (2) how does the metacognitive focus of anatomy educators change as they teach in a graduate-level gross anatomy course, and (3) how does metacognitive focus differ between anatomy educators based on teaching experience? All instructors involved in teaching the dissection laboratory sessions of D528 Anatomy for Healthcare Professionals during the summer of 2021 were invited to participate in this study. Participating instructors were asked to complete an education-specific metacognition awareness questionnaire prior to and towards the end of the course as well as multiple reflections on their teaching after each dissection session in which they taught.

3.3.2 Study Context: ANAT D528 Anatomy for Healthcare Professionals

This study was performed in the context of the D528 course, a graduate-level anatomy course designed to introduce allied health students to the basic concepts and structures of the human body (see Section 3.1.2 for full description). In this course, instruction is provided by a team of educators, which typically includes faculty members (n=4), associate instructors (AIs; n=2), and near-peer teaching assistants (TAs; n=6). All D528 faculty members have previously earned doctoral degrees in fields related to the anatomical sciences and currently hold appointments in the Department of Anatomy, Cell Biology, and Physiology at IUSM. The AIs are current doctoral students from the

Anatomy Education Track Ph.D. program and have received pedagogical training as part of their program of study. Lastly, TAs are second- and third-year DPT and OT students who applied to serve as TAs and were selected based on their previous D528 performance and responses within their application. As preparation for teaching, TAs were tasked with fully prosecting a cadaver under the supervision of a faculty member. Otherwise, formal pedagogical training was not provided to any instructors specifically for the purpose of teaching in D528 beyond a brief orientation with course policies.

During each laboratory session, instructors rotated between dissection groups to answer student questions and provide dissection assistance. At the end of each block, all instructors were also involved in tagging anatomical structures for the practical assessment.

3.3.3 Research Questionnaires

The metacognitive awareness of the instructors was captured at the beginning and end of the course using two questionnaires hosted online through Qualtrics. The pre-questionnaire included a demographics section (age, gender, teaching experience, and pedagogical training) as well as the Teacher Metacognition Inventory (TMI; Appendix D). The TMI, developed by Jiang et al. (2016) and based on the metacognitive principles described by Ben-David and Orion (2013), is a 28-question questionnaire designed to capture the metacognitive awareness of educators. The questionnaire includes the three overarching domains of Teacher Metacognitive Experience (TME), Teacher Metacognitive Knowledge (TMK), and Teacher Metacognitive Regulation (TMR). The TMK domain is further subdivided into Metacognitive knowledge of Self and

Metacognitive knowledge of Pedagogy, whereas the TMR domain is subdivided into Teacher Metacognitive Reflection, Teacher Metacognitive Planning, and Teacher Metacognitive Monitoring (Table 6). This questionnaire was chosen for use in this specific study because it is one of the two most widely used instruments for capturing teacher-related metacognition. Additionally, unlike the Metacognitive Awareness Inventory for Teachers (MAIT), the TMI closely parallels the structure of Flavell's revised model of metacognition and factors in all three dimensions of metacognition (see Section 2.1 for full description), simplifying data analysis and interpretation within the context of the model. After the instructors completed the pre-questionnaire, their individual scores along with instructions on how to interpret the scores were shared with them for in an effort to support their professional development.

Towards the end of the D528 course, participating instructors were invited to complete a post-questionnaire, which included the TMI once again. After completing the post-questionnaire, each instructor was presented with their individual TMI scores for their own professional development. Pre- and post- questionnaire responses were linked to a single individual for analysis using a unique user-generated identification code, however all data were then de-identified.

Table 6. Summary of Teacher Metacognition Inventory (TMI) Domains

Domain	Subdomain	Description
Teacher Metacognitive Knowledge	Metacognitive Knowledge about Self	Knowledge of one's own strengths and weaknesses as a teacher.
	Metacognitive Knowledge about Pedagogy	Knowledge of teaching practices, including their strengths/weaknesses, requirements, and goals as well as which would best fit a particular teaching scenario.
Teacher Metacognitive Regulation	Teacher Metacognitive Planning	Setting teaching goals, selecting appropriate instruction strategies, and making predictions for a future teaching session.
	Teacher Metacognitive Monitoring	In-the-moment awareness of student learning or the effectiveness of a teaching activity.
	Teacher Metacognitive Reflection	Evaluation of past teaching activities or outcomes, including identification of errors and successes and/or modification of teaching practices.
Teacher Metacognitive Experience		Feelings (familiarity, difficulty, knowing, confidence, satisfaction) or judgments (of learning, effort, or time) specifically related to teaching.

3.3.4 Post-Teaching Reflections

To capture the metacognitive awareness on a session-by-session basis and enrich the quantitative data collected through the TMI, instructors were asked to complete a series of teaching reflections after each dissection session in which they taught (Appendix E). The reflection activity was hosted through Canvas and consisted of four open-ended questions regarding how they felt about the most the most recent teaching session, what they believed they did well and didn't do well, and what they planned to do for the following teaching sessions. These questions were developed in consultation with the metacognition literature. Their aim was to encourage the instructors to engage with all three dimensions of metacognition, including metacognitive knowledge, regulation, and experience, in an effort to improve their teaching practices. Over the span of the semester, instructors may have completed up to 26 reflections (one per dissection session). Given that each session can be incredibly varied in teaching demands, reflections were assigned with high frequency to capture the instructors' metacognition on a session-by-session basis as well as to avoid recall-related issues. However, due to variance in participation, the number of completed reflections differed between instructors. Care was taken to ensure that identified themes were present across multiple individuals of a given group to ensure that instructors who taught more regularly or completed more reflections were not disproportionately represented in the data analysis.

3.3.5 Statistical Analysis

All TMI data were exported from Qualtrics and imported into SPSS analysis software for statistical analysis. Due to the small sample size, non-parametric statistical methods were used in the analysis. First, pre- and post-TMI scores for all participating instructors were compared using Related-Samples Wilcoxon Signed Rank test. Pre- and post-TMI data were then separated based on the participant's self-described experience (n=3; experienced, intermediate, and novice) and compared once again using Related-Samples Wilcoxon Signed Rank test. The pre- and post-TMI scores were then compared across the subgroups based on experience using the Kruskal Wallis H test. Lastly, the six TMI subscores were compared across the two timepoints using the One-Way Repeated Measures MANOVA. Results for all statistical analyses were considered significant if $p<0.05$.

3.3.6 Qualitative Analysis

Teaching reflections for each instructor were deidentified and imported into Dedoose qualitative analysis software. Initially, a deductive approach to thematic analysis was performed using codes derived from the TMI to facilitate integration of the quantitative and qualitative analyses. Afterwards, an inductive approach was performed to identify any themes unique to this participant population and dataset that were not initially captured with the deductive approach. Each round of thematic analysis was performed using the method described by Braun and Clarke (Braun and Clarke, 2006, 2013; Clarke et al., 2015; Braun et al., 2022). This method of thematic analysis involves six primary phases in an iterative process: (1) familiarization, (2) coding, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) reporting (see Section 3.1.5 for description of thematic analysis).

Table 7. Overview of Study Methods (Study #3)

Research Question	Data Collection	Data Analysis
(RQ1) What aspects of their teaching do anatomy educators focus on when they engage in metacognition while teaching in a graduate-level gross anatomy course?	• Post-teaching reflections	• Thematic analysis (deductive and inductive)
(RQ2) How does the metacognitive focus of anatomy educators change as they teach in a graduate-level gross anatomy course?	• Teacher Metacognition Inventory (TMI)	• Related samples Wilcoxon signed rank test • One-way repeated measures MANOVA
(RQ3) How does metacognitive focus differ between anatomy educators based on teaching experience?	• Teacher Metacognition Inventory (TMI) • Post-teaching reflections	• Kruskal Wallis H test • Thematic analysis (deductive and inductive), with focus on comparing themes across experience groups

3.4 Cross-Study Comparisons

A direct comparison of the metacognition of allied health students, medical students, and anatomy educators is not possible in this dissertation due to multiple differences between the research methods of each study. All three studies employed different quantitative instruments, which varied in the number and wording of question items, response options (e.g., dichotomous vs. Likert scale), timepoint of administration (e.g., pre- and post-course vs. pre- and post-exam), and intended purpose. Similarly, the methods of qualitative data collection differed in the number and wording of open-ended items, frequency and timepoint of administration, and intended purpose. The methods of qualitative data analysis also differed in their coding schema and overall approach to qualitative analysis (i.e., thematic analysis vs. framework analysis). These differences prevent a direct comparison across the three study populations.

Although the data collection methods were not in complete alignment, several aimed to capture similar elements of metacognition in their respective study populations. For example, both the first and second studies assessed the accuracy of allied health and medical students in predicting their exam performances albeit through slightly different means. In the first study, allied health students responded to a TopHat question regarding their anticipated exam performance on a five-point Likert scale (1=poor performance, 5=strong performance) after their second exam. The second study also assessed the assessed the ability of medical students to anticipate their exam performance but did so prior to their first exam and relied on a four-point close-ended scale. Both the first and second studies also asked students to metacognitively reflect on their exam performances and study strategies. However, the first study collected qualitative data using multiple Canvas-based discussion boards administered at different timepoints across an entire semester, whereas the second study relied on open-ended PBLI items administered prior to and after the first course exam. Therefore, any notable commonalities or trends present between the results of each study were identified and interpreted together, but a direct comparison across populations was not performed.

Table 8. Overview of Study Methods (Overarching)

Research Question	Data Collection	Data Analysis
(RQ1) What aspects of teaching and learning the anatomical sciences do students and educators focus on when engaging in metacognitive reflection?	• Metacognitive discussion boards • Practice-Based Learning and Improvement (PBLI) assignment • Post-teaching reflections	• Identification of commonalities and trends across study populations
(RQ2) How can additional awareness of metacognitive practices in both learners and educators contribute to anatomical sciences education for allied health and medical students?	• Metacognitive discussion boards • Practice-Based Learning and Improvement (PBLI) assignment • Post-teaching reflections	• Identification of commonalities and trends across study populations
(RQ3) Which previously described metacognitive principles, if any, are applicable to students and educators specifically in the anatomical sciences?	• Metacognitive discussion boards • Practice-Based Learning and Improvement (PBLI) assignment • Post-teaching reflections	• Identification of commonalities and trends across study populations

3.5 Trustworthiness Criteria

Three different methods of establishing trust were used to increase the rigor and credibility of the studies and their subsequent conclusions. First, methodological triangulation was performed through implementation of both qualitative and quantitative methods of data collection and analysis in each study. The first study included the quantitative data from MAI and qualitative data from the online discussion boards, the second study included both quantitative and qualitative data from the PBLIs, and the third study included quantitative data from the TMI and qualitative data from the reflective journals. The use of multiple methods simultaneously allows for each method to compensate for the shortcomings of the others, thereby increasing the credibility, dependability, and confirmability of the results (Shenton, 2004). Should multiple methods lead to the same conclusion, the conclusions drawn from these studies can be considered valid and trustworthy.

The studies also included multiple researchers during the data analysis and interpretation process to encourage peer scrutiny and inclusion of multiple, diverse perspectives. In all three studies, most research activities were performed by the primary researcher (A.S.C.), but at least one additional researcher of a different academic background and experience level were included during the data analysis and interpretation stages. These additional researchers offered constructive criticism on the research study, challenged the primary researcher's biases and preconceptions, and added fresh, diverse perspectives on the data, thereby increasing the credibility of the conclusions (Shenton, 2004).

Lastly, as the primary researcher, I maintained a reflexive commentary throughout the data analysis and interpretation processes and disclosed my own positionality as well as the positionalities of the additional researchers. Reflexivity is an iterative process of self-scrutinization of research procedures and decisions by the researcher (Bourke, 2014).

Maintaining a reflexive journal provided a longitudinal record that allows both the researcher and any external parties to scrutinize the researcher's initial impressions of the data, patterns identified, and theories generated during data analysis and interpretation, thus increasing credibility (Shenton, 2004; Bourke, 2014). Additionally, the positionalities of the researchers were also described in detail in the reflexive journal. Positionality is defined as the researcher's academic, cultural, and/or professional background in relation to those of the study participants. By disclosing the positionalities, the researchers can establish trust with the readers based on their qualifications. Moreover, the reader can be made aware of any potential biases or external factors that may influence the results of the studies. By using methodological triangulation, including multiple researchers, and disclosing reflexivity and positionality, readers and reviewers of these studies can trust the research was conducted under rigorous standards and the conclusions drawn are valid and credible.

3.5.1 Positionality Statement

These studies were conducted by researchers from the Department of Anatomy, Cell Biology, & Physiology at Indiana University School of Medicine. More specifically, the researchers are associated with the Anatomy Education Ph.D. Program, which focuses on training doctoral-level anatomy educators to teach the anatomical disciplines to undergraduate, graduate, or medical students and to produce high-quality educational research. The three researchers who performed the data analysis in one or more of the research studies are educators directly involved with the instruction of the courses in which the studies were conducted. I am a fourth-year doctoral candidate in the Anatomy Education Ph.D. Program with previous experience in educational research and teaching dissection-based gross anatomy. I was a student in Human Structure in 2019 and served as an associate instructor in the Human Structure course in 2020 and 2022 as well as in the D528 course from 2020-2022. M.A.M is an Associate Professor of Anatomy, Cell Biology, & Physiology and Vice-Chair for Education. She has directed the ANAT D528 course since 2018, taught in Human Structure on the Indianapolis Campus since 2017, and has extensive experience in educational research and teaching the anatomical sciences to allied health, medical, and graduate students. L.A.H is an Assistant Professor of Clinical Anatomy, Cell Biology, & Physiology on the Fort Wayne campus of IUSM. She is a graduate of the Anatomy Education Ph.D. Program and has directed the Human Structure course for the Fort Wayne Campus since 2016. Prior to the creation of the integrated Human Structure course, she was the course director of Medical Gross Anatomy at Fort Wayne in 2014 and 2015. She also has extensive experience in educational research and teaching the anatomical sciences to medical and graduate students.

3.6 Institutional Review Board Exemptions

All three studies described above have been reviewed and given exempt status by the Indiana University (IU) Institutional Review Board (IRB):

- Metacognition in Allied Health Students – Protocols #1804885093, 2004367557
- Metacognition in Undergraduate Medical Students – Protocol #1509117450
- Metacognition in Anatomy Educators – Protocol #11231

3.7 Chapter 3 Summary

In summary, this dissertation addresses its overarching and study-specific research questions through several multiple methods study designs. The first study, *Metacognition in Allied Health Students*, investigated the metacognitive practices of DPT, MPAS, and OTD students in a doctoral-level gross anatomy course using the Metacognitive Awareness Inventory (MAI) and Canvas-based metacognitive discussion boards. The second study, *Metacognition in First-Year Medical Students*, retrospectively reviewed the metacognitive practices and exam study strategies of first-year medical students, both repeating and non-repeating students, before and after their first integrated anatomy exam using the Practice-Based Learning and Improvement (PBLI) assignments. Lastly, the third study, *Metacognition in Anatomy Educators*, explored the metacognitive practices of faculty, associate instructors, and near-peer teaching assistants teaching in a gross anatomy through the Teacher Metacognition Inventory (TMI) and written post-teaching reflections. Due to the differences in the data collection methods used in the three described studies, direct comparison of the allied health students, first-year medical students, and anatomy educators was not possible. However, several relevant commonalities were identified across the groups by comparing similar quantitative items and themes identified from the metacognitive discussion boards, open-ended PBLI items, and post-teaching reflections. Several methods were also used to increase the rigor and credibility of the studies, including methodological triangulation, multiple researchers, and reflexive commentary. Together, these strategies increase the likelihood that the results and conclusions described Chapter 4: Results and Chapter 5: Discussion and Conclusions, respectively, are trustworthy and credible.

CHAPTER 4. RESULTS

4.1 Metacognition in Allied Health Students

4.1.1 Participant Demographics

A total of 109 (84%) and 59 (46%) allied health students completed the pre- and post-MAI, respectively, resulting in 52 matched pairs (40%). This sample population included 41 DPT students, 35 MPAS students, and 33 OTD students. The average of the participating students was 23.3 years old. Regarding gender, 16% identified as male whereas 84% identified as female. A more detailed breakdown of participant demographics can be found in Table 9. The demographics of the matched pairs were similar to and representative of the overall population of participating students.

Table 9. Summary of Participant Demographics (Allied Health Students)

	Doctor of Physical Therapy (DPT)	**Master's of Physician Assistant Studies (MPAS)**	**Doctor of Occupational Therapy (OTD)**	**Total**
Population	41 (38%)	35 (32%)	33 (30%)	109
Average Age	22.7(±2.6)	24.4(±2.6)	22.7(±2.5)	23.3(±2.6)
Gender				
Female	33 (36%)	27 (29%)	32 (35%)	92
Male	8 (47%)	8 (47%)	1 (6%)	17
Highest Earned Degree				
Master's	1 (25%)	2 (50%)	1 (25%)	4
Bachelor's	40 (38%)	33 (31%)	32 (30%)	105

4.1.2 Metacognitive Awareness Inventory (MAI)

A significant increase in student metacognition was found following course completion, particularly related to conditional knowledge, information management strategies, and evaluation. Average MAI scores were similar between pre-course

(40.4±5.6) and post-course questionnaires (42.8±4.9). However, when pre- and post-questionnaires were individually linked, students exhibited a statistically significant 2.7% increase in mean total MAI score from 40.9±5.3 to 42.0±4.9 ($p<0.001$) (Figure 1). Among MAI subcategories, conditional knowledge improved from 4.4±0.8 to 4.6±0.6 ($p=0.02$), information management strategies improved from 8.1±1.3 to 8.6±1.2 ($p=0.02$), and evaluation improved from 3.3±1.4 to 4.0±1.4 ($p=0.001$). However, neither pre- nor post-course MAI scores were correlated with individual examination grades. Furthermore, individual change in MAI score between the pre- and post-course scores exhibited a weak, negative correlation ($r=-0.30$) with discussion board response frequency ($p=0.03$). On average, DPTs were found to participate in the metacognitive discussion boards (7.5±3.3) more frequently than both the MPASs (4.5±3.4, $p=0.01$) and the OTDs (4.3±3.2, $p=0.01$).

Figure 1. Pre- vs. Post-Course MAI Score (Paired)

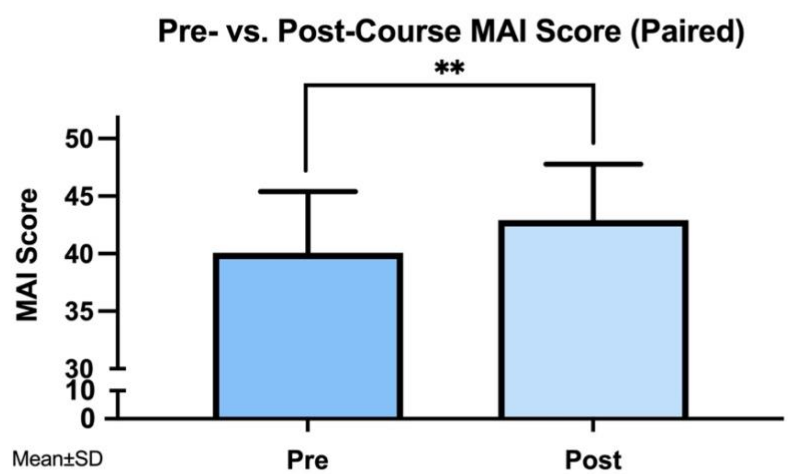

Figure 1. Individually-linked pre- vs. post-course MAI scores. A statistically significant increase ($p<0.001$) was identified between the pre- and post-course MAI scores linked to a single individual, suggesting an improvement in metacognition. ** = $p<0.01$

4.1.3 TopHat Question

Overall, students felt they accurately predicted and felt satisfied with their performance on the course summative assessments. TopHat participation ranged from 90-95% of students throughout the course. When asked to anticipate their examination grades on a five-point Likert scale (1=poor performance, 5=strong performance), students averaged 3.1±1.0 on Block 1, 3.4±1.0 on Block 2, and 3.0±1.0 on Block 3. Furthermore, students rated their resulting examination satisfaction as 3.6±1.2 for Block 1, 4.1±1.1 for Block 2, and 3.3±1.2 for Block 3 on a five-point Likert scale (1=very dissatisfied, 5=very satisfied). On a dichotomous scale, DPTs were found to monitor their progress (1.9±0.3) more frequently compared to their MPAS counterparts (1.7±0.5, $p=0.01$), but not their OT counterparts (1.8±0.4, $p=0.19$) (Figure 2). Students also rated the difficulty of learning anatomy at 1.9±0.9 on a three-point scale (1=easy, 3=difficult).

Significant positive correlations were found between anticipated and actual assessment performance, as well as satisfaction with one's performance and actual assessment performance. Anticipated and actual examination grades were moderately and positively correlated for all evaluated Blocks; Blocks 1 ($r=0.60$, $p<0.001$), Block 2 ($r=0.60$, $p<0.001$), and Block 3 ($r=0.60$, $p<0.001$). Examination satisfaction was also strongly and positively correlated with actual examination grades for all evaluated blocks; Blocks 1 ($r=0.87$, $p<0.001$), Block 2 ($r=0.76$, $p<0.001$), and Block 3 ($r=0.67$, $p<0.001$).

Figure 2. Progress Monitoring by Program of Study

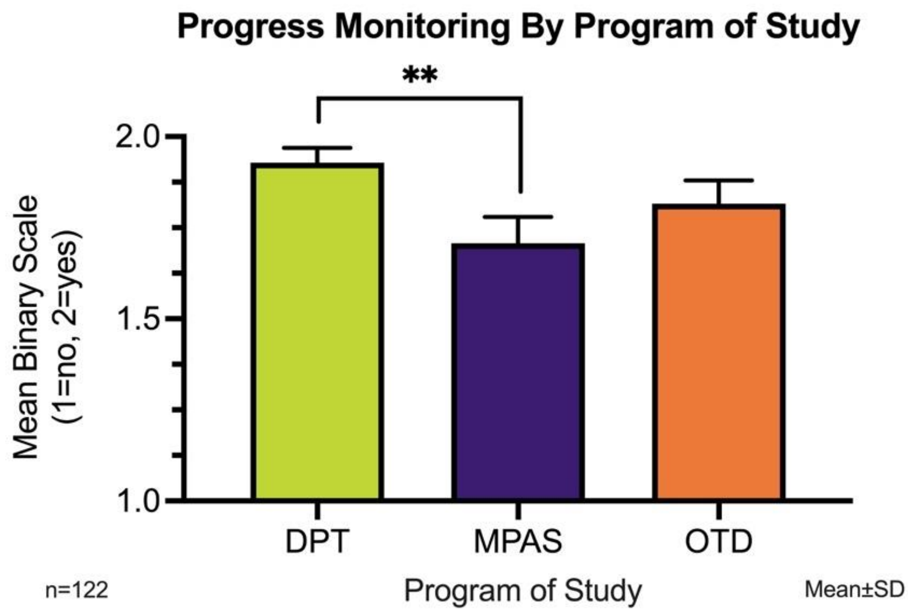

Figure 2. Mean binary response (1 = no; 2 = yes) of students, separated by program, regarding whether they monitored their learning progress. DPT students were found to monitor their progress significantly more than their MPAS colleagues (p=0.01), but not their OTD counterparts (p=0.19). DPT = Doctor of Physical Therapy program; MPAS = Master of Physician Assistant Studies program; OTD = Doctor of Occupational Therapy program. ** = p<0.01

4.1.4 Comparison by Performance Tercile

Average Block examination performance differed significantly across all three performance terciles (p<0.001). In regard to MAI score, statistically significant differences were identified in the Declarative Knowledge subcategory only, with high-performers exhibiting higher scores than middle- and low-performers in both the pre (p=0.04) and post-course (p=0.01) surveys.

When TopHat responses were compared across performance terciles, those who passed the assessments were able to anticipate such adequate grades, while those who scored lower were unable to anticipate such scores and were also dissatisfied (Figure 3).

In Block 1, both high and middle performers anticipated similarly strong examination performances that were significantly higher than low performers ($p<0.001$ and $p=0.001$ respectively). Similarly, in Block 2, high and middle performers predicted strong examination performances compared to their low performer peers ($p<0.001$ and $p=0.002$ respectively). Lastly, in Block 3, the high and middle performers once again anticipated stronger examinations than the low performers ($p<0.001$ and $p=0.004$ respectively). However, all three terciles varied significantly from each other in their examination satisfaction (Figure 3). For Block 1, high performers were the most satisfied followed by the middle performers and then the low performers ($p<0.001$). Similar differences in satisfaction were also identified in Block 2 ($p<0.001$). On Block 3, high performers were significantly more satisfied than both middle ($p=0.006$) and low ($p<0.001$) performers, who were similarly satisfied (Table 10).

Table 10. Anticipated Exam Performance and Satisfaction by Performance Tercile

	Performance Tercile		
	High	**Middle**	**Low**
Anticipated Exam Performance			
Block 1	3.4±0.9	3.3±0.9	2.5±1.1
Block 2	3.9±0.9	3.5±0.8	2.8±1.0
Block 3	3.4±0.9	3.1±1.1	2.4±0.9
Exam Satisfaction			
Block 1	4.6±0.6	3.9± 0.7	2.3±1.1
Block 2	4.7±0.8	4.3±0.8	3.3±1.2
Block 3	3.9±1.2	3.1±1.4	2.6±1.1

Figure 3. Block Examination Perception by Performance Tercile

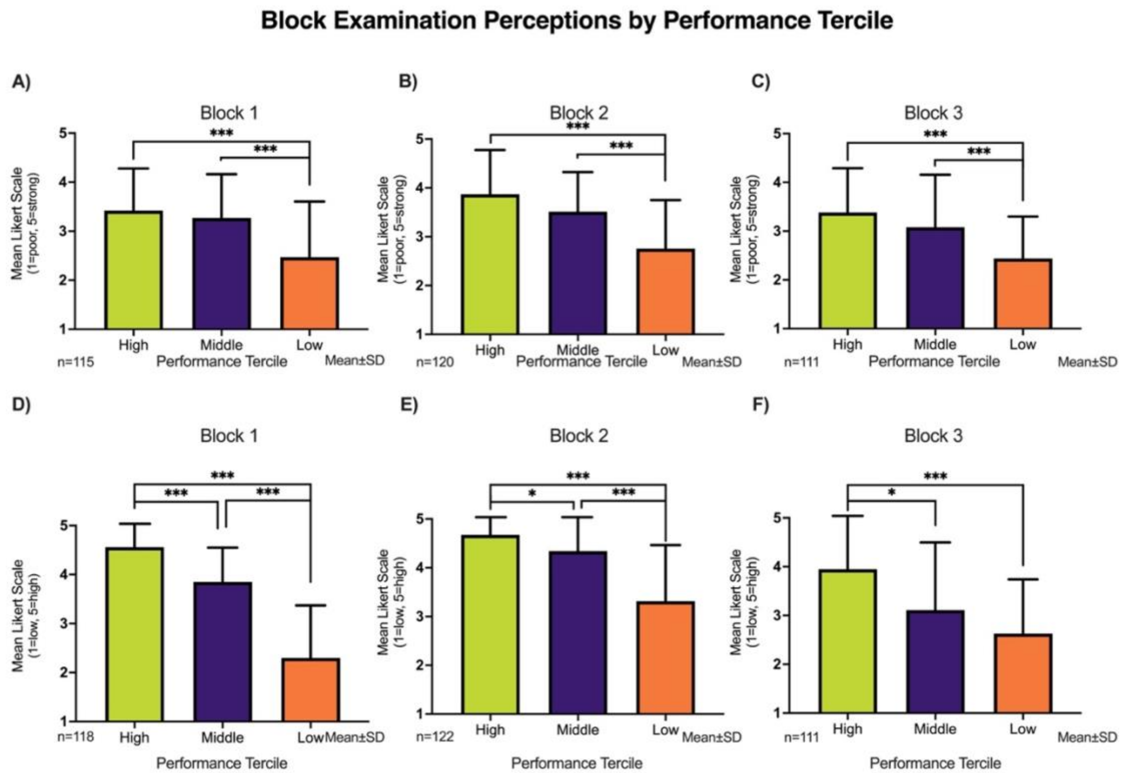

Figure 3. Anticipated examination performance and examination satisfaction 5 = strong performance/high satisfaction; 1 = poor performance/low satisfaction) by performance tercile for each Block evaluated. High and middle performers anticipated similarly strong examination performances that were significantly higher than low performers for Blocks 1 ($p<0.001$ and $p=0.001$ respectively), Block 2 ($p<0.001$ and $p=0.002$ respectively), and Block 3 ($p<0.001$ and $p=0.004$ respectively). However, all three terciles varied significantly from each other in their examination satisfaction for Blocks 1 ($p<0.001$) and Block 2 ($p<0.001$). On Block 3, high performers were significantly more satisfied than both middle ($p=0.006$) and low ($p<0.001$) performers, who were similarly satisfied. High = top 33% of performers in overall course; Middle = middle 33% of performers in overall course; Low = lowest 34% of performers in overall course. * = $p<0.05$; *** = $p<0.001$

4.1.5 Discussion Board Themes

Participation in the metacognitive discussion boards ranged from 97% to 22% of students per topic, with a steady decline over time. Several overarching themes were identified through thematic analysis of the various discussion boards, including: **Preferred Study Strategies** and **Examination Reflections**.

Preferred Study Strategies. Overall, students most frequently mentioned physical note-taking and repetitive processes as their preferred study strategies. Repetitive study strategies involved either rote repetition (e.g. re-writing notes) or purposeful repetition (e.g. watching a lecture once to preview and again to take thorough notes) and often varied in their perceived effectiveness.

> "Sometimes I would just go through the powerpoint slides and read the slides over and over hoping information would stick in my head but it didn't. I quickly realized that this was not an effective study strategy for myself."

As they studied, students most often gauged their learning through quizzing and basic recall (e.g. practice questions and flashcards). However, as the course progressed, students reported monitoring their learning less frequently due to time constraints and concurrent course load.

> "I was doing a good job at monitoring my learning at the beginning but as more information piled on, I was just focused on understanding and organizing the material."

Additionally, students cited time constraints as a major factor that influenced their choice of study strategy.

> "It took me a VERY long time to take written notes while listening to the lecture because of how many times I paused it, so it felt like I was spending way too much time taking notes and writing everything down rather than actually studying and absorbing the material."

Examination Reflections. Analysis of post-examination reflections revealed that student receptiveness to modifying their study strategies declined throughout the course. After Examination 1, most students indicated they were satisfied with their performance, but noted there was still room for improvement. The most common errors involved test comprehension (e.g., misreading questions, lack of specificity, and/or lack of confidence) and specific anatomical concepts.

> "Overall, I am pretty happy with my exam performance, but there are definitely some tips that I could follow to have a better grade on the next exam. Some questions I missed could have been avoided by studying the spine more in-depth and overall I could have started reviewing the material more in advance."

Several students noted a willingness to change their study habits and identified specific strategies to address their needs.

> "I definitely struggled with the nervous system type questions as they related to the flow of efferent and afferent nerve signals. I didn't dedicate very much study time to this topic and I did poorly in that section. I plan to adjust my study habits to include flashcards while watching the lectures instead of using the PowerPoints to create them."

After Examination 2, many students reported an improvement in their examination performance and attributed the improvement to modifications of their study strategies.

> "Over the course of transitioning from Block 1 to Block 2, I found that fully rewriting my notes by hand really helped me to solidify the more particular details in my brain and also helped to cross check that I am understanding the overarching major topics."

However, after Examination 3, fewer students indicated satisfaction with their examination performance or mentioned modifying their study strategies. Additionally, student identification of areas of improvement and strategies to address them became less specific and diverse. Instead, students preferred to "double down" on strategies they had used previously by "studying more" or "practicing more" moving forward.

> "For this next exam, I know I need to study even more and try to really know the information and learn it."

> "I mainly missed identification questions. This did not surprise me as I have always had a hard time identifying nerves in the pelvis area. I just need to practice this more."

4.2 Metacognition of First-Year Medical Students

4.2.1 Participant Demographics

A total of 1802 first-year undergraduate medical students enrolled in the Human Structure course at Indiana University School of Medicine completed the PBLI assignment between 2016 and 2020. This population included 1751 medical students who successfully passed their first-year courses on their first attempt as well as 51 medical students who failed and were required to repeat the first year in its entirety. A more detailed breakdown of participant demographics can be found in Table 11.

Table 11. Summary of Participant Demographics (Undergraduate Medical Students)

	Repeating Students	**Non-Repeating Students**	**Total**
Population	51 (2.8%)	1751 (97.2%)	1802
Cohort			
2016	-	354 (20.2%)	354
2017	11 (21.6%)	333 (19.0%)	344
2018	18 (35.3%)	346 (19.8%)	364
2019	14 (27.5%)	356 (20.3%)	370
2020	8 (15.7%)	362 (20.7%)	370

4.2.2 Repeating Undergraduate Medical Students

Generally, medical students who would ultimately go on to fail and repeat Human Structure were overconfident, dissatisfied, and inaccurate when predicting their first anatomy examination scores on their unsuccessful attempt but scored higher and were more accurate and satisfied on their second, repeat attempt. On their initial attempt, repeating students scored an average of 59.4%±8.8 on their first examination, predicted scores between the "Pass" and "High Pass" ranges (2.7±0.8), rated their confidence between "Low" and "Moderate" (2.7±0.6), and were mostly dissatisfied with their exam performance (1.1±0.3). When Spearman's Rho was applied, no statistically significant correlations were identified between predicted score, confidence, and satisfaction. On their repeat attempt, repeating students scored 77.0%±8.4 on average, predicted similarly strong scores in the "High Pass" range (3.0±0.7), but rated their confidence between "Moderate" and "High" (3.3±0.5) this time, and were mostly mixed in their satisfaction (2.1±0.9). When Spearman's Rho was applied to predicted score, confidence, and satisfaction from the second attempt, only predicted score and confidence exhibited a statistically significant, positive correlation ($r=0.43$, $p=0.003$). In a comparison to the repeating students' initial and repeat attempts, actual exam score, confidence, and satisfaction ($p<0.001$) all exhibited statistically significant improvements whereas predicted score remained consistent (Figure 4).

Figure 4. Close-Ended PBLI Responses of Repeating Medical Students (1st and 2nd Attempts)

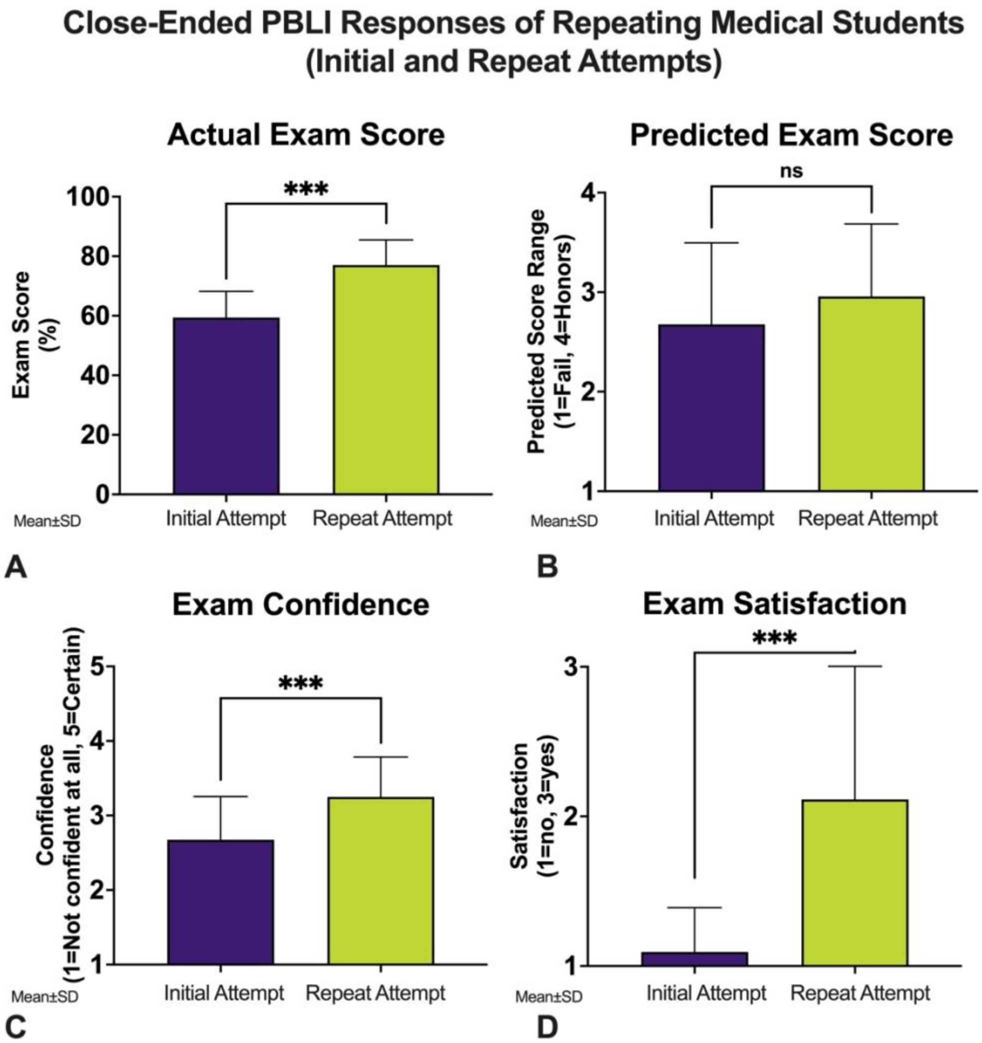

Figure 4. Close-ended PBLI responses of repeating medical students (Initial and Repeat attempts). Repeating students were overconfident, dissatisfied, and inaccurate when predicting their exam performance on their first attempt but were more successful on their second attempt. Between their initial and repeat attempts, the repeating medical students significantly increased their actual exam scores, confidence, and satisfaction ($p<0.001$), whereas predicted exam score remained fairly consistent. Actual Exam Score: 0-100%. Predicted Exam Score: 4 = >92% ("Honors"); 3 = 85-91% ("High Pass"); 2 = 70-84% ("Pass"); 1 = <70% ("Fail"). Confidence: 5 = Certain; 4 = High Confidence; 3 = Moderate Confidence; 2 = Low Confidence; 1 = Not at all confident. Satisfaction: 3 = Yes; 2 = Not Sure; 1 = No. * = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$.

Several overarching themes were identified through framework analysis of the aggregated pre- and post-exam PBLIs from the repeating students' initial, unsuccessful attempt only, including: **Enhance Existing Study Strategies**, **Time is Precious**, **Back to the Anatomy Lab**, and **Practice Questions: A Double-Edged Sword**.

Enhance Existing Study Strategies. After the first examination, the majority of students who ultimately would go on to repeat the course believed they needed to either expand an existing study strategy or implement it earlier to succeed in the course rather than dramatically alter how they studied:

> "I'm going to continue going to lectures but I'm now really making sure I address the learning objectives beforehand."

> "I will still continue to rely primarily on the lecture slides but I plan to supplement that with textbook readings and practice problems to cement my understanding."

Time is Precious. Initially, repeating students noted that they were unclear as to what they should focus their studies on. This lack of direction caused students to dedicate study time towards any topic they thought could be tested in the examination:

> "I determined I needed to learn everything that was presented by the professors."

> "I knew that I did not know much, so I just studied everything."

After the first examination, several repeating students felt that they needed to manage their time more effectively in several different ways. Some students believed they needed to study more consistently to avoid falling behind or cramming:

> "Block 1 did not go well with me because I ended up cramming for it. I definitely will not be making the same mistake for block 2. I've realized

> keeping up with the material and periodically reviewing the structures we find in lab is the best way to be successful."

> "Above all else though, I must not fall behind like I did for Block 1. I must keep up as much as I reasonably can with the material, otherwise studying the majority of the information on the week of the test will be a disaster like it was last time."

Other students noted that their study time would be better would be better spent focusing on assessing their knowledge rather than passively reviewing all presented material equally:

> "I will also resist the temptation to stay reviewing the PowerPoint slides for extended periods of time, like I did last time, leaving me no time to practice my knowledge."

Back to the Anatomy Lab. Many repeating students indicated they needed to study in the anatomy lab more frequently:

> "Next, I will reshuffle my schedule to accommodate even more lab hours to concentrate on learning rather than dissecting."

Several also found the anatomy lab helpful in integrating lecture and lab material:

> "This time, I want to better integrate lecture and lab studying more. I feel that studying the location/appearance of things simultaneously with the lecture notes will make better use of my time."

Practice Questions: A Double-Edged Sword. Most repeating students used practice questions in their study strategies. However, this strategy had varying degrees of success. Some found practice questions useful for self-assessment:

> "I didn't have enough time to do many practice questions. Because I wasn't applying the knowledge I had learned it was a difficult for me to assess the information that I knew."

Conversely, students who relied too heavily on practice questions weren't able to develop sufficient foundational knowledge to make self-assessment useful:

> "I spent a disproportionate amount of time studying the [Board Review Series] books and testing myself with questions too early and therefore using them to learn (inefficiently) rather than assess."

4.2.3 Non-Repeating Undergraduate Medical Students

Unlike their repeating peers, non-repeating medical students as a whole were moderately confident, somewhat satisfied, and more accurate when predicting their first anatomy examination scores. On average, non-repeating students scored 80.2%±10.1 on their first examination, predicted scores near the "High Pass" range (2.9±0.8), mostly rated their confidence as "Moderate" (2.9±0.6), and mostly rated their satisfaction as mixed (2.2±0.9) (Table 12). Non-repeaters also exhibited statistically significant correlations between actual examination score, predicted score, confidence, and satisfaction ($p<0.001$). Linear regression determined that predicted score was a statistically significant ($p<0.001$) predictor of actual score and accounted for small amount of variance ($r=0.178$, adjusted $R^2=0.03$).

Table 12. Close-Ended PBLI Responses of Non-Repeating Medical Students

	PBLI Responses
	Non-Repeating Students
Actual Exam Score (0-100%)	80.2%±10.1
Predicted Exam Score (1=Fail, 4=Honors)	2.9±0.8
Exam Confidence (1=Not confident at all, 5=Certain)	2.9±0.6
Exam Satisfaction (1=no, 3=yes)	2.2±0.9

When non-repeaters were organized based on performance tier, each tier was found to be largely inaccurate in predicting their first examination scores. Linear regression determined that predicted score was no longer a statistically significant predictor of actual score for any of the individual pass tiers. Roughly 37% of “Honors” students (n=62) accurately predicted their examination scores would fall in the “Honors” range. Similarly, 49% of “High Pass” students (n=248) predicted a score in the “High Pass” range, 34% of “Low Pass” students (n=275) predicted a score in the “Low Pass” range, and 4% of “Fail” students (n=10) predicted a failing score (Table 13).

Top performing students (n=61) were found to be moderately confident, very satisfied, and underestimated their abilities when they predicted their first examination performance. On average, the top performing students scored 96.0%±1.5, predicted scores in the “High Pass” range (3.0±0.8), rated their confidence as slightly above “Moderate” (3.2±0.5), and were mostly satisfied with their examination performance (2.8±0.6).

Table 13. Performance Tier Distribution of Non-Repeating Students

		Performance Tier				
		Honors (>92%)	**High Pass (85-91%)**	**Pass (70-84%)**	**Fail (<70%)**	**Total**
Expected Examination Score	**>92%**	62 (37%)	151 (30%)	170 (21%)	52 (19%)	435
	85-91%	68 (41%)	248 (49%)	345 (43%)	108 (39%)	769
	70-84%	36 (22%)	102 (20%)	275 (34%)	108 (39%)	521
	<70%	0 (0%)	6 (1%)	10 (1%)	10 (4%)	26
	Total	166	507	800	278	1751

Several overarching themes were identified from the top-performing students' pre- and post-exam PBLIs through the framework analysis method, including: **Metacognitive Regulation**, **High Adaptability**, and **"If It Ain't Broke, Don't Fix It"**.

Evidence of Metacognitive Regulation. Top-performing students frequently demonstrated evidence of metacognitive regulation in their reflections, particularly by planning, monitoring, and evaluating their studying. These students regularly self-assessed themselves and preferentially focused their studying on topics they self-identified as gaps in their knowledge rather than studying all topics evenly:

> "I've been addressing my learning needs by testing myself on what I need to know to determine what material I do know and what I still need to do studying on and focusing on the material that I don't know well enough to recall. I have found the resources that allow me to identify which topics I actually know (versus recognize on [PowerPoint] slides) are the most helpful."

> "Anything that I have trouble remembering, have to re-review, or get wrong on practice questions I consider an area of weakness that I need to work on. I also tried to quiz my classmates and have them quiz me about anything that came to mind. Whatever was difficult to remember immediately revealed an area that I needed to strengthen."

Moreover, top-performing students also used study strategies that were grounded in metacognitive principles such as concept mapping and making connections across the material:

> "I tried to mentally map the regions of the body in my head, and when I had trouble I knew that I needed to spend more time with those areas."

> "I have relied on the list of structures/terms that we need to know and then try to tie each of those individual items together to understand the big picture. For example, when working through the arm I started with the bone osteology of the humerus, then tied in how the muscles attach related to those landmarks. I then moved on to the muscle's action, innervation, and blood supply. Once I have a good foundation, I begin working through

> clinical questions to apply my knowledge and figure out which areas need more focus."

High Adaptability. Several top-performing students noted that they quickly recognized that their approach to studying was ineffective for the course and adjusted accordingly, suggesting high adaptability:

> "I think that I approached the first part of the Block 1 Exam like I did for undergrad-very careful to catch every detail, letting nothing fall through the cracks the first time. I learned quickly that this didn't work because we had far too much stuff to go over for that meticulous approach to be sustainable."

> "I think I will do a cost-benefit analysis on the various resources and methods of studying. For example, while there is benefit to rewatching a lecture for a third time, the amount of new knowledge gained in that hour will probably not equal the amount gained from doing an hour of practice questions or from watching a different video on the subject."

"If It Ain't Broke, Don't Fix It". After receiving their first examination scores, the majority of top-performing students indicated their satisfaction with their performance and noted that they would minimally change their approach to studying, if at all:

> "I will preserve all of my approaches that I used to study for Block 1. In terms of modifications, I am planning to do more practice problems, especially since I anticipate that this upcoming exam will be more difficult than the previous one due to the material about the pelvis. However, I feel like my overall study strategies are pretty good so I do not think I will change much. Only time will tell if whether this is a case of "If it ain't broke, don't fix it" or a case of complacency."

> "Because of my high performance on exam 1, I do not plan on making any immediate, major changes to my study approaches. But, I am open to changing my study approaches if, at any time, one or more of these approaches ceases to be effective".

When top-performers did intend to adjust their study strategies, most of their modifications involved time management such as starting to study earlier or improving the efficiency of their studying:

> "I will preserve all of my approaches from Block 1 studying since I was very happy with how I did, but I will be getting rid of my approach of re-watching lectures because I think it took up a lot of time without yielding much new information being learned."

> "I have tried to streamline my note taking to be more efficient since I felt like I was wasting time by being jumbled during the last block. I also found myself reviewing content that I had already mastered too often during last block. I would burn half an hour studying a couple PowerPoints that I already knew by heart instead of trying to get ahead by watching the next day's lecture and I have tried to improve on that during preparation for block 2 exam."

4.2.4 Comparison of Top-Performing and Repeating Students

Initially, both top-performing students and repeating students predicted similar scores ($p=0.62$), but top-performing students ultimately earned significantly higher examination scores ($p<0.001$) and were significantly more confident ($p<0.001$) and satisfied ($p<0.001$) than their repeating peers. When the top-performing students were compared against the repeating students' repeat attempt, both groups were similarly confident and predicted similar scores, but top-performing students still earned significantly higher scores ($p<0.001$) and were significantly more satisfied ($p<0.001$) than their repeating peers.

4.3 Metacognition in Anatomy Educators

4.3.1 Participant Demographics

A total of 13 (52% of invited) instructors participated in this study between 2021 and 2022. This population included five (100%) faculty members, three (60%) associate instructors, and five (33%) near-peer teaching assistants. Regarding gender, 67% of all female-identifying instructors (n=12) and 14% of all male-identifying instructors (n=1) opted to participate. A more detailed breakdown of participant demographics can be found in Table 14.

Table 14. Summary of Participant Demographics (Anatomy Educators)

	Faculty	**Associate Instructors**	**Near-Peer Teaching Assistants**	**Total**
Population	5 (100%)	3 (60%)	5 (33%)	13 (52%)
Teaching Experience				
>7 years	5 (100%)	-	-	5 (38.5%)
4-6 years	-	3 (100%)	-	3 (23.0%)
>3 years	-	-	5 (100%)	5 (38.5%)
Gender				
Female	4 (80%)	3 (100%)	5 (100%)	12 (92.3%)
Male	1 (20%)	-	-	1 (7.7%)
Not Specified	-	-	-	0 (0%)

4.3.2 Teacher Metacognition Inventory (TMI)

Overall, the teaching-related metacognition of the D528 instructors improved after a semester of teaching dissection-based gross anatomy, particularly in the subdomains of Teacher Metacognitive Reflection and Metacognitive Knowledge about Self. Between the start and end of the course, the average TMI score of all instructors combined significantly improved from 108.8±12.0 to 114.3±8.4 (p=0.046) (Figure 5). When the TMI subdomain scores were compared, only the subdomains of Teacher

Metacognitive Reflection (TMR) and Metacognitive Knowledge about Self (MKaS) exhibited statistically significant changes across the semester. The TMR subdomain improved from 25.5±4.0 to 28.2±3.5 ($p=0.018$) whereas the MKaS subdomain improved from 16.1±2.3 to 17.0±2.0 ($p=0.027$) (Figure 6). All other subdomains remained nearly constant or exhibited non-significant improvements.

Figure 5. Total TMI Score (All Instructors)

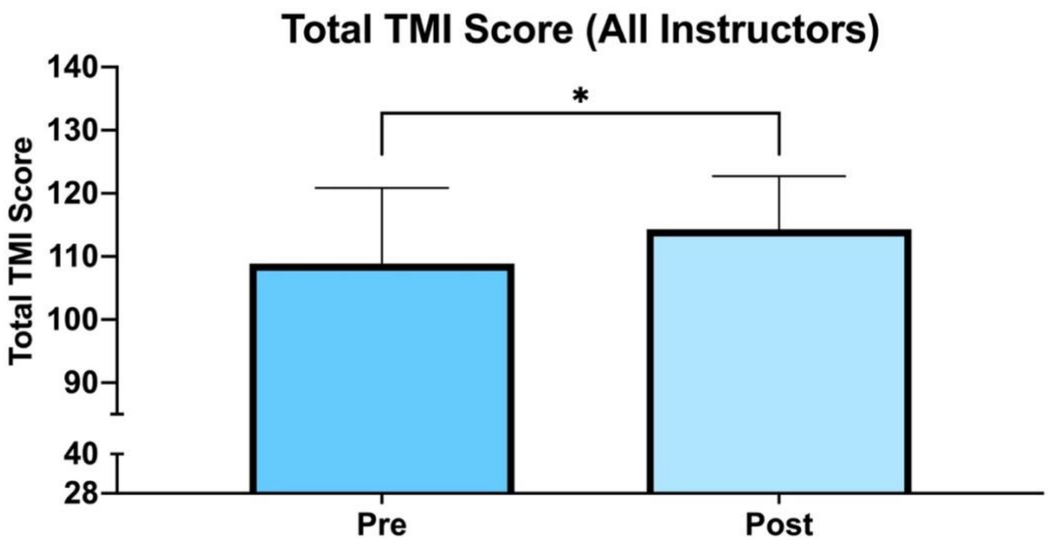

Figure 5. Total TMI Score (All Educators). As a whole, the educators significantly improved their total Teacher Metacognition Inventory (TMI) scores between the start and end of a semester teaching dissection-based gross anatomy ($p=0.046$). The TMI is a 28-item survey instrument designed to capture the metacognitive awareness of educators. Responses are on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree), resulting in a minimum score of 28 and maximum score of 140. * = $p<0.05$.

Figure 6. TMI Subscores (All Instructors)

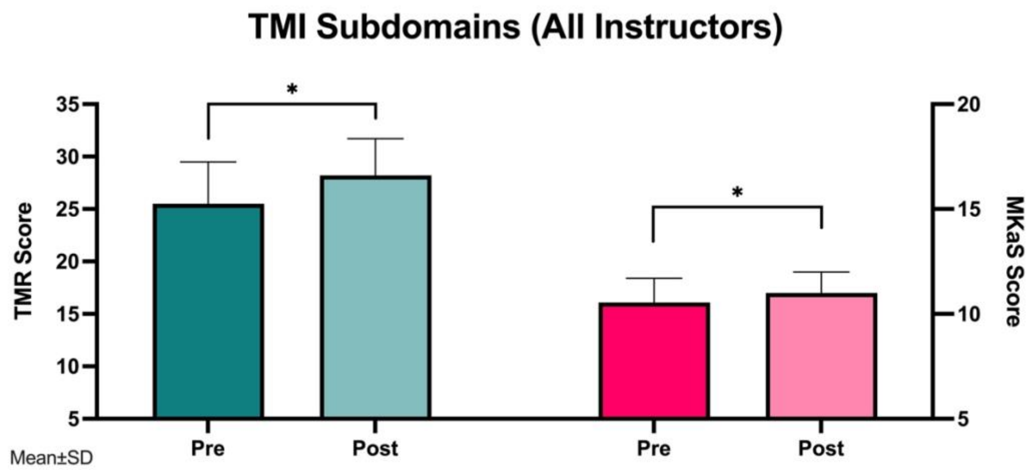

Figure 6. TMI Subdomains (All Educators). When the TMI scores of the instructors were separated into its subdomains and compared, only the subdomains of Teacher Metacognitive Reflection (TMR) and Metacognitive Knowledge about Self (MKaS) exhibited statistically significant changes. Responses are on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree), resulting in minimum scores of 5 for both TMR and MKaS and maximum scores of 35 and 20 for TMR and MKaS, respectively. * = $p<0.05$.

The average TMI scores for faculty members, associate instructors, and near-peer teaching assistants did not significantly differ from each other either at the beginning or the end of the semester ($p=0.95$ and 0.177, respectively). When TMI scores were separated based on the instructors' prior teaching experience, only the near-peer teaching assistants demonstrated a statistically significant improvement in their metacognition. Near-peer teaching assistants significantly improved their average TMI scores from 98.8±8.8 to 110.2±6.1 ($p=0.043$) (Figure 7). When TMI scores were broken into its subdomains for each group, no statistically significant changes were identified.

Figure 7. Total TMI Score by Experience

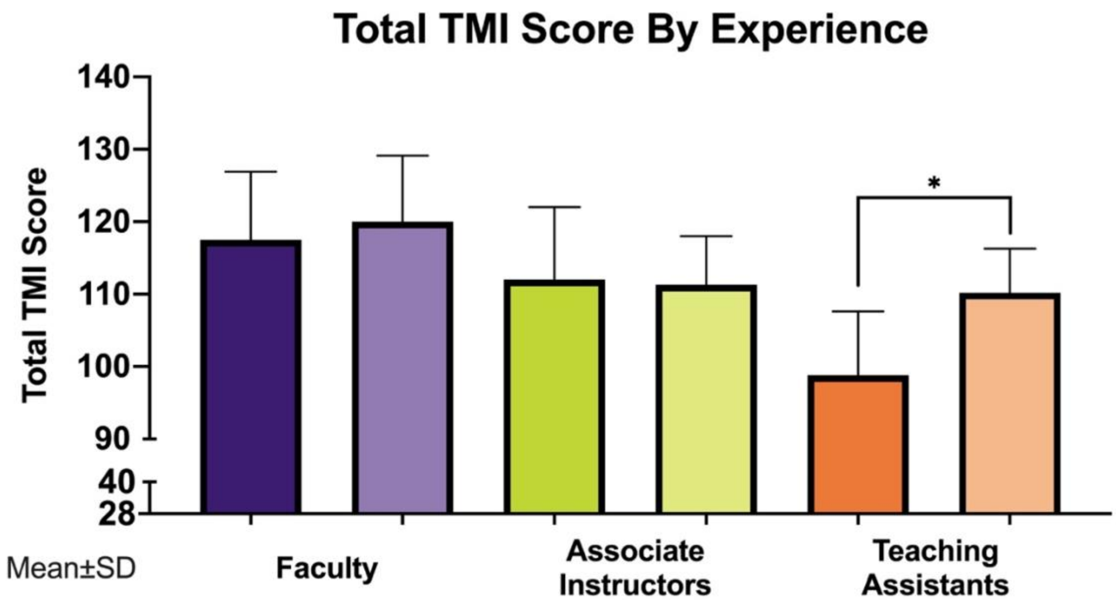

Figure 7. Total TMI Score by Experience. The teaching assistants exhibited a statistically significant improvement in their total TMI scores (p=0.043). The TMI is a 28-item survey instrument designed to capture the metacognitive awareness of educators. Responses are on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree), resulting in a minimum score of 28 and maximum score of 140. * = p<0.05.

4.3.3 Post-Teaching Reflective Journals

One major theme, **Increasing Metacognitive Self-Knowledge**, was identified through deductive thematic analysis of the post-teaching reflective journals using codes derived from the Teacher Metacognition Inventory (TMI).

Increasing Metacognitive Self-Knowledge. The educators demonstrated varied awareness of their abilities as educators depending on their teaching experience. Faculty, who were the most experienced, seemed firmly aware of themselves as educators:

> "I talk quickly and there were probably times I needed to slow down and read the students a little better. I make assumptions that all students have prepared and it was clear from some questions I was asked that not all students prepared. (Faculty #1)

> “I need to be better about asking students their names and introducing myself when I first approach their table. I don't think I did this once today. I tend to be more problem-oriented and focus on addressing student questions/concerns.” (Faculty #3)

The moderately experienced associate instructors also demonstrated some awareness of themselves as educators:

> “Especially with the heart and other organs we remove from the body cavities, I have a tendency to hold the organ and point out structures without first orienting it or at least saying ‘we're looking at the posterior side’.” (AI #1)

> “I've noticed that I can be very "in the zone" when I'm hunting for structures, generally resulting in my silence, which can sometimes be awkward when it takes me a long time to uncover something, whether it be from their lack of cleaning or my own slow progression. During those times, I could definitely talk to them more and give them a more in-depth knowledge base on the structure and surrounding structures.” (AI #3)

However, the novice TAs seemed less aware of themselves as educators, often developing their teaching style during a laboratory session by observing other educators:

> “I did hear [Faculty] using the phrase, "how do you know that, that structure is what you say it is? What evidence shows you that?" And I think that is a great tool to use to ask students that. In the future, I want to use that more, and I plan to.” (TA #3)

> “I think I could have referred some of the students that were struggling with the dissection to other groups that had identified a majority of the structures. I saw another instructor do this and it seemed successful with the groups explaining and the group seeing the structures.” (TA #5)

Two themes were also identified using an inductive approach to thematic analysis, with the data driving code generation from the bottom up. These themes include: **Metacognitive Focus** and **Self-Criticality**.

Metacognitive Focus. Although all educators were tasked with teaching the same material, they varied significantly in what they focused on while teaching. As a group, the near-peer teaching assistants were more teacher-centered and internally focused on their own content mastery:

> "Per usual, should have prepared better. For this session, I only had time to review the lecture, which I now think is the least helpful tool to help in the lab." (TA #1)

> "I think I could have done a better job of reviewing my arteries and veins of the heart before the lab. I spent time reviewing prior to the lab, but not enough to where I was fully confident when addressing all the questions that students had." (TA #2)

Conversely, the more experienced faculty associate and instructors were all much more learner-centered and externally focused on factors beyond their content mastery. Each focused on a different factor that also impacted student learning such as: inclusive language, respectful donor treatment, student-teacher rapport, and pedagogical techniques.

Inclusive Language:

> "I did a good job at modeling how to use neutral language to discuss genital structures. I attempt not to assign a male or female sex to any structures but instead use person-first language." (Faculty #1)

Respectful Donor Treatment:

> "I've been thinking recently about the importance of modeling consent in the lab in the form of asking students if they are ready to do something and describing what is about to happen (e.g. "we're going to cut the ribs so you might hear some cracking sounds, is everyone ready for that?") so they can prepare instead of just going ahead with it…This might be helpful in demonstrating how they should be continually getting consent from their patients when they are treating them in their respective clinical practices." (AI #1)

Student-Teacher Rapport:

> "I was better about at least asking for names! I certainly don't remember most of them, but I was able to start making connections between those who have been emailing me regularly ("ohhh, that's you!")." (Faculty #2)

Pedagogical Techniques:

> "I think I did a good job of bringing students into my demonstrations. This was something I had noted in previous sessions that I would like to do more of - having students identify structures as I'm demonstrating how to approach finding neurovasculature, or showing them where to cut/probe/etc. and having them do it as I described what we were looking for. They seemed very engaged with this method, and I think it boosted their confidence in dissection techniques to not have me do everything for them." (Faculty #4)

Self-Criticality. The educators also differed in how self-critical they were of their teaching. The TAs were often overly critical of themselves when they made an error or struggled to answer a question. However, their self-critiques and perceived lack of knowledge were often unfounded:

> "I could have been more confident in my own abilities. I was helping a table that was trying to dissect the femoral triangle but was struggling to find the femoral a.v. I knew it was found within the femoral sheath, so I used that knowledge to eventually find the femoral a. However, when it came to locating the femoral v., I began to doubt my ability to find it and asked an instructor for help. I actually could have found all of the structures myself, which is where I need to have more confidence." (TA #4)

Although the faculty also occasionally made errors or forgot specific details, they were less harsh and viewed them as learning opportunities:

> "As I teach more varied content …it's natural and inevitable to forget some details and I use it as an opportunity to show students there is always room for learning and repetition is 100% necessary." (Faculty #1)

> "I could have prepared better so the information was at the forefront of my brain at the start of lab - wasn't a hinderance, but may have been quicker on the recall at the beginning of lab." (Faculty #3)

4.4 Cross-Study Results

Two noteworthy commonalities were identified between the allied health and medical students. First, the highest performing students in both groups accurately predicted strong exam performances with greater accuracy than their lower performing peers. Across the first three block exams, the top tercile of allied health students consistently predicted strong exam performances and subsequently scored the highest, giving them greater accuracy than their peers (Table 10, Figure 3). Similarly, in the second study, the "Honors" and "High Pass" groups (representing roughly the top tercile of HS students) accurately predicted their first exam performance would mostly fall within the "Honors" (>92%) and "High Pass" (85-91%) ranges, whereas their lower performing peers were less accurate (Table 13).

Both the allied health and medical students also appeared to "double down" on their preferred, existing study strategies, albeit at different points in the course. As demonstrated by the metacognitive discussion boards in Section 4.1.5, the allied health students opted to forgo continuously monitoring and modifying their study strategies in favor of familiar study strategies due to mounting responsibilities that piled on across a semester. First-year medical students also experienced a similar "doubling down" effect as shown in Sections 4.2.2 and 4.2.3. Overall, the medical students resorted to doubling down on their familiar strategies much earlier in their anatomy course, with repeating students waiting until they received feedback from their first exam, whereas the top 3% of medical students doubled down based on their own determination of their study strategy effectiveness.

4.5 Chapter Summary

In summary, the studies performed in this dissertation provide several insights into the metacognition of allied health students, medical students, and anatomy educators. In the first study, *Metacognition in Allied Health Students*, the students as a whole exhibited a statistically significant increase in their total MAI score, suggesting an improvement in their overall metacognition. When the students were separated based on program of study, the MAI scores of each group were similar to one another with no individual group exhibiting statistically significant changes to their MAI scores. However, when TopHat responses were compared, DPT students reported monitoring their learning the most, followed by the OTD students, and then the MPAS students, which may be related to the concurrent course load of each program of study. A similar theme was also identified through thematic analysis of the Canvas-based metacognitive discussion boards. Students were more open to monitoring and modifying their study strategies early in the course, but as the course progressed and other academic responsibilities competed for their time, students often resorted to "doubling down" on familiar, but potentially less effective study strategies.

In the second study, *Metacognition in First-Year Medical Students*, students who initially failed and repeated Human Structure were generally overconfident, dissatisfied, and inaccurate when predicting their first anatomy examination scores on their unsuccessful attempt but scored higher and were more accurate and satisfied on their second attempt. Conversely, non-repeating medical students were moderately confident, somewhat satisfied, and more accurate when predicting their first anatomy examination scores. Several themes were also identified through framework analysis of the PBLI responses, including enhancement of existing study strategies, time management, emphasis on the anatomy lab, and misuse of practice questions for repeating students and evidence of metacognitive regulation, high adaptability, and adherence to existing study strategies for non-repeating students.

Lastly, in the third study, *Metacognition in Anatomy Educators*, the educators exhibited a statistically significant increase in their TMI scores between the start and end of the gross anatomy course. When the educators were separated based on their teaching experience, only the near-peer teaching assistants demonstrated a statistically significant improvement in their MAI scores, whereas faculty and associate instructors remained fairly consistent. Thematic analysis of the post-teaching reflections also determined that experienced educators were more outwardly focused, self-aware, and accepting of personal shortcomings, whereas novices were more inwardly focused, less self-aware, and hyper-critical of themselves.

Two interesting commonalities were also identified across the three study populations. As seen in the first and second studies, higher performing students were more adept at predicting their exam performances compared to their lower performing peers. Both allied health and medical students also seemed to “double down” on familiar study strategies as their gross anatomy courses progressed, albeit at different timepoints. In the following chapter, the study-specific and overarching results will be interpreted in the context of the existing anatomy education and metacognition literature. Several educational recommendations will also be put forth based on the conclusions drawn from the studies.

CHAPTER 5. DISCUSSION AND CONCLUSIONS

5.1 Preface to Discussion and Conclusions

Metacognition, the ability to monitor and regulate one's own learning and performance, is an essential skill that provides numerous benefits both students and educators. Multiple studies have demonstrated that metacognitive skills can improve critical thinking, enhance learning, improve task performance, increase the accuracy of self-evaluation, and foster growth mindsets across several populations and contexts (Naminule and Corebima, 2018; Lazendic-Galloway et al., 2019; Stanton et al., 2019; Menekse et al., 2022; Martin-Piedra et al., 2023). More specifically, metacognition can help students perform better on assignments and assessments, aid educators in teaching more effectively and dynamically, and support the clinical reasoning of clinicians (Kuiper and Pesut, 2004; Ali and Yasmeen, 2019; Royce et al., 2019; Siqueira et al., 2020; Chang, 2021; Honeycutt et al., 2021; Menekse et al., 2022). However, few studies have explored metacognition specifically in the context of anatomical sciences education. Therefore, this dissertation was designed to explore the metacognitive practices of allied health students, first-year medical students, and anatomy educators as they learned and taught the anatomical sciences. Each of the three multiple method studies employed a combination of quantitative questionnaires and survey instruments as well as qualitative reflective writing activities to assess the metacognition of the study populations. These studies identified several interesting results relating to metacognition in the context of anatomical sciences education. The following sections of this chapter will interpret these results and discuss their implications in conjunction with the existing metacognition, education, and anatomical sciences literature. Several educational recommendations will also be presented to improve the how the anatomical sciences are taught and learned in the future.

5.2 Metacognition in Allied Health Students

This first study provides key insights into the metacognitive development of allied health students in a graduate-level gross anatomy course, specifically during COVID-19 online learning, during which students were immediately forced to increasingly rely on their own metacognitive skills (Anthonysamy, 2021). While overall metacognition improved across the semester, execution of those metacognitive skills was heavily influenced by time constraints, and study strategy modifications were mostly implemented early in the course. Moreover, metacognition varied based on academic performance. As such, this work provides recommendations for implementing a metacognitive activity within readers' own courses.

Several results, both quantitative and qualitative, indicate that students had improved their metacognitive skills by the end of the semester. This improvement in metacognition is consistent with previous studies, but generally, the literature remains inconclusive on the stage at which students typically improve their metacognition during health professional education (Siqueira et al., 2020). In previous studies with undergraduate medical students, MAI scores did not differ significantly over the span of an academic year (Hong et al., 2015) or between first- and fifth-year medical students (Welch et al., 2018). However, another study found that the MAI scores of medical students in their clinical phase were significantly higher than those of their pre-clinical counterparts (Turan et al., 2009). As such, additional research is necessary to determine if and how metacognition evolves during health professional education as well as what factors may influence this change in metacognition. In the present study, the increased in MAI score that was identified was relatively small, and may represent an incremental step in their progressive metacognitive growth during their allied health education. As a lifelong skill, metacognition can be continuously improved, particularly with consistent practice and when an individual encounters novel challenges at different stages of their education and careers (Hong et al., 2015). Therefore, continued engagement with other metacognitive activities throughout students' curriculum as well as their transition between the didactic and clinical phases of their education will likely encourage further metacognitive growth in the future (Turan et al., 2009; Hong et al., 2015).

Thematic analysis of discussion board responses supports that students were engaging in metacognition during the course. Students were able to weigh the strengths and weaknesses of a particular study strategy and identify specific areas of improvement based on their examination performance as well as new study strategies to address their weaknesses. After the Block 2 examination, students reported these study modifications led to improved examination performance. However, by the Block 3 examination, students were reluctant to perform these metacognitive practices, instead preferring to "double-down" on existing strategies. Students may have felt their modified strategies would suffice for all subsequent examinations, leading them to monitor and modify their studying less frequently moving forward. This intentional pause in metacognition has been documented previously in third-year undergraduate medical students (Versteeg et al., 2021). Some students found metacognitive skills to be unnecessary and preferred to rely on inefficient study strategies due to their perception that medical education was based solely on the memorization (Versteeg et al., 2021). It should be noted that in the present study, students were unable to see classmates' responses to the discussion prompts until they themselves had responded. This method prevents students from experiencing bias from social comparison (Raat et al., 2013) or simply reading and copying the previous responses from their classmates. It also requires them to metacognitively reflect on their own learning prior to responding to the discussion post, at which point, they are able to review their classmates' responses and incorporate any methods that their classmates may be using into their own learning strategies.

Mounting academic and professional responsibilities may have also contributed to the students' reluctance to change study strategies. As noted in the discussion boards, students were able and willing to monitor their learning early in the semester, but over time, concurrent coursework forced them to divide their limited time. Given that increased educational stress and cognitive workload can negatively impact metacognition (Byrne, 2013; Saricam et al., 2017), the added stress and effort of juggling these additional responsibilities likely contributed to the students' reluctance to practice metacognition. This hypothesis is further supported by the finding that the DPT students, who had no concurrent courses, participated in the metacognitive discussion boards and reported monitoring their learning more frequently than their MPAS classmates, who had to contend with an additional 13 credit hours of coursework. Therefore, the DPT students had more time to devote to practicing and honing their metacognition for one course, whereas the MPAS students had to divide their time amongst several different courses. Interestingly, DPT students engaged in metacognitive practices such as monitoring significantly more frequently than their MPAS colleagues, suggesting there should have been a difference in overall metacognitive ability between the two groups. This discrepancy may suggest a difference in metacognitive *practice* between the groups rather than a difference in actual metacognitive *ability*, further supporting the conclusion that concurrent coursework and time constraints contributed to the difference in monitoring learning. Medical educators are constantly faced with the challenge of teaching more and more content in the same amount of time; a feat that is inherently impossible. Others have posited that improving students' metacognitive skills should be a greater focus in medical education moving forward so that students may become flexible learners who are able to deal with the rapidly changing world of medicine and the uncertainty and complexity that comes with those changes (Eichbaum, 2014; Veersteeg et al., 2021).

While previous studies have shown that reflective writing can improve student metacognition (Stanton et al., 2015; Alt and Raichel, 2020; O'Loughlin and Griffith, 2020), the present study found a negative correlation between MAI score and discussion board participation. The more a student engaged with the discussion boards, the lower they scored on the MAI. This negative correlation will require further investigation, but a few potential explanations can be offered. First, the negative correlation may be related to students' pre-course MAI scores. Students who scored low on the MAI at the beginning of the course may have turned towards the discussion boards to improve their metacognition, thus prompting them to participate more frequently. Another explanation involves how students used metacognition to evaluate themselves. Regular discussion board participation could have improved student metacognition, leading students to evaluate themselves lower, but more accurately, on the MAI. Furthermore, the differences in course load between the three cohorts may have also played a role, preventing some students from participating in the online discussion boards as much as they would have liked.

This study also identified variations in metacognition between performance terciles. High and low performing students were both able to accurately evaluate their learning (or lack thereof) and predict their examination performance. High performing students consistently predicted high, scored high, and thusly were the most satisfied, while low performing students predicted low, scored low, and were the least satisfied. Conversely, middle performers predicted strong performances, but only scored moderately well and were moderately satisfied, possibly due to overestimation of their knowledge and abilities. This suggests that middle performers exhibit the largest metacognitive disconnect, which is inconsistent with previous studies that have identified low-performing students as demonstrating the most significant metacognitive disconnect due to the Dunning-Kruger effect (Ehrlinger et al., 2008; Kruger and Dunning, 1999; Sawdon and Finn, 2014; Steuber et al., 2017). Declarative knowledge within the present allied health student population was the only element of the MAI where high, middle, and low performers differed and may be the source of the differences in evaluation accuracy. Declarative knowledge includes factual knowledge of the content being learned, oneself as a learner, and factors that may influence one's performance such as learning goals or assessment criteria (Lai, 2011). High performers have the largest foundation of knowledge on which to base their self-evaluations, giving them a more accurate self-evaluation overall. Low performers have the smallest foundation of knowledge, but since their knowledge gaps are so large, they are likely acutely aware of their shortcomings, and therefore recognize how unprepared they are for the examinations. Middle performers may have reached a point at which they have accumulated just enough knowledge to feel fully prepared for the examination, but are still somewhat unaware of their shortcomings, thus overestimating their abilities.

5.3 Metacognition in Undergraduate Medical Students

This second study provides key insights into how first-year undergraduate medical students, particularly top-performing and repeating medical students, perceived their examination preparation strategies and performance before and after their first integrated anatomy examination. As a whole, undergraduate medical students were able to predict their examination performances with moderate accuracy. Qualitative inquiry revealed that there were significant metacognitive differences in how repeating and top-performing students perceived and used their study strategies. Repeating students sought to improve their studying by modifying their existing study strategies, managing their time more effectively, and taking better advantage of the gross anatomy laboratory. Conversely, top-performing students were more metacognitive and highly adaptable, but once they identified an effective study strategy, they were unlikely to make any further changes.

Quantitative analysis of closed-ended PBLI responses and first examination scores demonstrated that undergraduate medical students have limited metacognitive ability to accurately predict their examination performance. As a whole, non-repeating medical students were able to somewhat predict their examination performances, but when the student population was separated into tiers based on performance, no individual tier was able to accurately predict their examination performance with statistical significance. Students who ultimately went on to repeat the course and students who fell into the “Fail” tier (<70%) on just the first exam often overestimated their abilities and predicted strong performances whereas top-performing students in the “Honors” tier (>92%) often underestimated their abilities and anticipated weaker performances. This mismatch between predicted and actual examination performance across all pass tiers suggests some degree of metacognitive disconnect, possibly related to a lack of declarative knowledge (see Section 5.1). Declarative knowledge, a key component of metacognition, is defined as knowledge of oneself as a learner and factors that may influence their performance such as learning goals or assessment criteria (Lai, 2011). Given that the first examination was most students’ first professional-level examination and included unfamiliar testing modalities such as “bell-ringer” style practical examinations, most students likely did not fully know what to expect regarding difficulty and expectations. This gap in their declarative knowledge may have impaired their metacognitive ability to accurately predict their performance. As such, students may have been able to accurately gauge their own knowledge, but not necessarily how that knowledge would translate to performance on the examination. Particularly in the case of repeating students and/or those that fell in the “Fail” tier, the metacognitive disconnect may have been exacerbated by the Dunning-Kruger effect (Kruger and Dunning, 1999; Sawdon and Finn, 2014; Steuber et al., 2017). This cognitive bias causes individuals with limited knowledge to significantly overestimate their performance due to an inability to recognize their own deficiencies (Kruger and Dunning, 1999). Therefore, the repeating students likely not only lacked declarative knowledge regarding the examination, but also metacognitive awareness of their own deficiencies, further impairing their ability to make accurate judgments about their exam preparedness.

Both repeating and top-performing students also relied heavily on practice questions to prepare for the first examination, but the difference in how they used these practice questions suggests a discrepancy in their metacognitive ability. Practice questions are well-documented as a popular and effective study strategy in the medical education literature (Deng et al, 2015; Nayak and Erinjeri, 2008; Roediger et al., 2011; McNulty et al., 2012; Mains et al, 2015; Naujoks et al; 2022; Wenger, et al., 2009). However, the benefits of practice questions are highly dependent on how they are incorporated into a student's overall study plan. Completion of practice questions allows students to metacognitively monitor and evaluate their current level of knowledge, including any gaps in knowledge (Naujoks et al., 2022). Each subsequent set of practice questions completed improves the accuracy of the students' judgments of their knowledge, providing them with a better idea of their examination preparedness (Naujoks et al., 2022). This usage of practice questions is more in line with how the top-performing students used practice questions in their own studies. As noted in the PBLI excerpts, top-performing students regularly self-assessed their own knowledge using a variety of resources, including learning objectives, flashcards, and practice questions. As a result, these students were more aware of their gaps in knowledge and could focus their studying on addressing these gaps, making their studying more efficient and effective overall. Conversely, some repeating students used practice questions to learn the material in the first place rather than for self-assessment. While this approach can help students improve their knowledge base (Naujoks et al., 2022), it may be too inefficient when compared to other methods for building a foundational knowledge base with sufficient depth and breadth.

Qualitative analysis of the repeating and top-performing students' PBLI reflections also indicate a difference in metacognitive monitoring between the two groups, leading to a difference in their adaptability. Individuals who are more adept at metacognitive monitoring are typically more cognitively adaptable as well (Haynie et al, 2012). As noted previously, top-performing students demonstrated this skill more frequently by using self-testing appropriately to assess their knowledge. This consistent self-testing likely gave these students a better grasp of their knowledge as well as what study strategies worked and did not work for them. These more informed students could then adjust how they studied accordingly prior to the examination rather using the examination itself as a means of receiving feedback on their study strategies. Conversely, repeating students often committed to a particular study strategy until they received feedback in the form of their examination scores, and even then, the students opted to enhance the existing strategy rather switch to something different. This "doubling down" on a familiar study strategy rather than exploring other potential strategies was also documented in the allied health students. As stress and fatigue mounted, the allied health students preferred to rely on familiar, but less effective strategies because they lacked the time to risk exploring new strategies. As noted by Picton and colleagues (2022), some struggling medical students fall into an "at capacity" group and are quickly overwhelmed by the pace and volume of self-regulated learning in medical school. Many of the repeating students likely fall into this category and were overwhelmed from the beginning, leading them to fall back onto their familiar, less effective study strategies to try and keep pace.

Most medical students also considered time management to be a significant factor that influenced how they chose and used their study strategies. Repeating students noted they wanted to improve their time management by studying early or more consistently whereas top-performing students focused more on improving their efficiency. Several studies have noted that time management is an essential skill for medical students (Shah et al., 2010, West and Sadoski, 2011; Hill et al, 2018). Time management has been found to be a significant predictor of academic performance, with first-year medical students who are skilled in time management performing significantly stronger than their peers (West and Sadoski, 2011). Additionally, time management provides non-academic benefits by supporting mental well-being and reducing burnout (Barbosa et al, 2016).

5.4 Metacognition in Anatomy Educators

Overall, the gross anatomy educators improved their metacognition across a semester of teaching dissection-based gross anatomy. This metacognitive growth was primarily in the educators' reflective ability and their knowledge of themselves as educators. When the educators were separated based on teaching experience and pedagogical training, the near-peer teaching assistants were the only group to exhibit a significant improvement in their metacognition. Qualitative analysis of the post-teaching reflective journals demonstrated that the educators focused on different aspects of teaching and learning depending on their teaching experience. Novice instructors such as the TAs were more self-critical and teacher-centered in their reflections, primarily on their own content mastery. Conversely, experienced instructors such as the AIs and faculty were less self-critical and more learner-centered in their reflections, mainly on additional factors that impact student learning. Some of these factors were broadly applicable to educators as a whole whereas others were specific to the anatomical sciences, which suggests that gross anatomy educators employ both domain-general and domain-specific metacognitive practices. With these results in mind, several recommendations can be made to support the metacognitive development of gross anatomy educators at different levels such as content reviews for novices or DEI and communications training for experienced educators (see Section 5.6.3 for full description of educator recommendations).

As indicated by the significant increase in TMI score, the anatomy educators improved their teaching-related metacognition across a semester of teaching gross anatomy, particularly in their ability to reflect on their teaching and their awareness of their own strengths and weaknesses as educators. The educators' metacognitive growth can be largely, though not completely, attributed to the post-teaching reflective journals. Regular engagement in the reflective journal likely improved the educators' familiarity and proficiency with critical reflection, leading to a higher score in the Teacher Metacognitive Reflection subdomain of the TMI. Moreover, regular critical reflection through journaling likely provided the educators with greater insight into themselves and their teaching abilities, resulting in a higher score in the subdomain of Metacognitive Knowledge about Self. Several previous studies support these results and have demonstrated that critical reflection through journal writing can improve the metacognition of educators (Kaminski 2003; Phelps et al., 2004; Gikandi, 2013; Cengiz and Karatas, 2015). Through reflective journaling, educators can familiarize themselves with the process of critical reflection and better pinpoint specific areas of improvement in their teaching, thus allowing them to tailor their professional development to their unique needs (Phelps et al., 2004). In addition to the metacognitive benefits, reflective journaling has also been shown to increase educator motivation and self-confidence (Cengiz and Karatas, 2015).

Although the participating educators improved their metacognition and identified specific areas of improvement, it may not necessarily result in improved teaching practices if they fail to act. Some educational experts argue that while reflection is a necessary part of educator development and should be encouraged, identification of a weakness via reflection does not always lead to concrete actions to address said weakness (Beauchamp, 2015). Other critiques include lack of genuine reflection by the practitioner, narrowness of approaches to reflection, problematic ethical considerations, and structural limitations on reflection (Beauchamp, 2015). Therefore, critical reflection represents an essential first step towards improved teaching, but educators must also learn how to execute appropriate pedagogical changes as well. This disconnect between awareness and execution can be addressed by implementing programs that make a stronger connection between metacognitive theory and practice, resulting in educators who are more comfortable with applying theory to their teaching after critical reflection (Stenberg et al., 2016).

When TMI scores were separated based on teaching experience, the novice near-peer teaching assistants, exhibited the largest and only statistically significant improvement to their metacognition. This difference in metacognitive growth likely stems from each educator group's initial awareness of their own teaching abilities. The TAs began the semester with limited to no teaching experience unlike their faculty and AI colleagues (Table 14). As such, the TAs likely had less knowledge of their own teaching abilities, which was reflected in their pre-course TMI scores. Faculty had the highest initial average TMI score (117.0±9.4), followed by the AIs (112.0±10.0), and then the TAs (98.8±8.8). Given their limited experience, the TAs may have been in a formative stage of their training. At this stage, small amounts of experience may have disproportionately large improvements in their teaching practices. Conversely, more experienced educators have already established their own preferred style. These individuals might aim to fine tune their teaching rather than develop it from the ground up, leaving them with less room for growth by comparison. Given the significant growth that can be achieved, those interested in the development of anatomy or medical educators should focus on developing the metacognitive and pedagogical skills of these novices while they are still in this formative stage of their educator training. A small investment in the pedagogical development of these educators could lead to significant benefits both in their immediate teaching and in the individuals' future careers.

The qualitative analysis of the post-teaching reflective journals also demonstrated that the metacognitive focus of novice educators differed greatly from those of more experienced educators. The TAs, who all had little to no teaching experience, were more teacher-centered and focused internally on their own content mastery rather than content delivery or student interactions. This teacher-centered focus on content mastery may be due to the TAs' diminished recall of the course material. As second- and third-year DPT students, the TAs are at least one year removed from the course. During that time, they may not have meaningfully used or rehearsed their anatomical knowledge, resulting in poor retention. For example, after one year removed from their initial gross anatomy course, the average medical student loses 14.7%±11.7% of their anatomical knowledge (Custers 2010; Doomernik et al., 2017). Additionally, due to the COVID-19 pandemic and the interruption of in-person dissection labs in 2020, some TAs did not have the opportunity to dissect a human donor from beginning to end. These TAs may have a weaker foundation of anatomical knowledge and minimal dissection experience to draw upon while teaching (Thompson and Marshall, 2019; Ross et al., 2020). Conversely, AIs and faculty teach gross anatomy year-round, providing them with numerous opportunities to rehearse and reinforce their anatomical knowledge. Together, these factors may have substantially diminished the TAs' anatomical knowledge, causing them to prioritize and fixate on their content mastery in their reflective journals.

Unlike the near-peer teaching assistants, the more experienced educators were more learner-centered in their reflections and externally focused on additional factors beyond content mastery that could impact student learning. This difference in focus is reasonable given that the faculty and AI already have a strong mastery of the content. As such, they likely have greater confidence in their content mastery and could instead focus on other factors that impacted the learners and how they engage with the material. This finding is consistent with previous studies which have shown that as educators gain teaching experience, they become more metacognitive and transition from being more teacher-centered in their teaching to being more learner-centered (Rao et al., 2017).

Beyond differing from the TA group as a whole, each of the AIs and faculty differed from each other as well and had their own unique focus that they fixated on in their reflective journals. Some of these educational fixations included inclusive language, student-teacher rapport, respectful donor treatment, and pedagogical practices. However, it is unclear as to why each educator chose to fixate on a specific topic and prioritize it in their teaching. These fixations may originate from the individual's personal morals or teaching philosophy. Although many of these fixations were not directly related to the course content, they encompassed several relevant and important issues in the anatomy community. (Kumar and Kumar, 2019; Easterling and Byram, 2022). Given their diverse educational priorities, more experienced educators may be benefit from professional development centering on diversity, equity, and inclusion (DEI), pedagogy, or communications depending on their unique interests.

Interestingly, although all members of the teaching team were invited to participate in this study in both 2021 and 2022, mostly female educators opted to participate. This discrepancy in participant gender may be related to how education as a profession is perceived by society. Due to its cultural perception as a low-status profession, teaching has become a gendered field with women dominating the profession and comprising roughly 76% of teachers at the K-12 levels (Wong, 2019). Although all the educators were involved with teaching, the male educators may not have identified as teachers, instead viewing themselves as researchers or clinicians first and teachers secondarily (Trent, 2014). Clinicians often find their clinician and educator identities in conflict with one another. For those that prioritized their clinician identity, teaching was viewed as a low-complexity, low-priority activity that was not highly valued for continuing professional development (Starr et al., 2006; Cantillon et al., 2019; van Lankveld et al., 2021). These individuals may not have viewed improving their teaching-related metacognition and teaching skills as necessary for their future careers as clinicians or researchers. However, it is beyond the scope of this study to determine how an educators' self-identified gender impacted their decision to participate in teaching-focused professional development.

5.5 Metacognition Across Allied Health and Medical Student Populations

Although a direct comparison between the metacognition of allied health and undergraduate medical students is not possible due to differences in data collection and analysis methods between the first and second studies, several notable commonalities are worth discussing. First, top performing allied health and medical students (the top tercile as well as "Honors" and "High Pass" groups, respectively) were both able to predict their examination performances with greater accuracy when compared to their lower performing peers. As noted previously, this comparatively high accuracy is likely related to the students' declarative knowledge. This element of metacognition is defined as the factual knowledge of the content being learned, oneself as a learner, and factors that may influence their performance such as learning goals or assessment criteria (Lai, 2011). Metacognitive knowledge, including declarative knowledge, is considered to be one of the more important elements of metacognition because it serves as the basis for other metacognitive processes (Tarricone, 2011). Top performing groups from both populations likely have greater declarative knowledge compared to their peers to base their metacognitive judgments, making their predictions more accurate. This conclusion is supported by the results of the pre- and post-MAI scores of the allied health students in the first study, in which the top tercile of students scored the highest in the declarative knowledge subdomain. Given its potential relationship with strong academic performance and accuracy of performance predictions, educators may want to support the development of their students' declarative knowledge, specifically.

Additionally, both allied health and medical students opted to "double down" on preferred study strategies at some point during their anatomy courses. At this "doubling down" point, the students opted to maintain or minimally modify their familiar study strategies rather than continue to explore other study strategies. This effect can be attributed to time and energy constraints, which both allied health and medical students have noted as a precious, limited commodity. In the case of the allied health students, this doubling down occurred steadily across a semester due to mounting academic responsibilities that competed for their time. Conversely, first-year medical students doubled down much earlier, around the time of their first examination. Repeating medical students opted to maintain a preferred set of strategies until they received feedback in the form of their examination scores, and then made minor enhancements afterwards. Top performing medical students also chose to double down on a preferred set of study strategies after they deemed them as effective enough, even at the risk of becoming complacent. However, since the PBLI assignments were not administered at multiple time points throughout the course, it is unclear if the receptiveness of medical students to modifying their study strategies continues to change over time. This difference in doubling down time may once again be related to the students' competing academic and professional commitments. In the case of the allied health students, the MPAS students, who had the largest concurrent course load, resorted to doubling down more readily, whereas the DPT students who did not have any concurrent coursework had more capacity to continue monitoring their learning and doubled down less readily. Several factors likely placed the first-year medical students under similarly high pressure. Unlike the D528 course that the allied health students were enrolled in, Human Structure is an integrated anatomy course, which required students to learn histology and embryology in addition to the gross anatomy content. Prior to 2020, the medical students were also concurrently enrolled in an additional seven credit hours of molecular and cellular biology, totaling 15 credit hours. After 2020, the medical students were only required to enroll in three additional credit hours, but Human Structure was compressed from 16 weeks to 9 weeks. These additional pressures may have pushed the medical students to double down on their study strategies earlier than their allied health counterparts. An awareness of this doubling down effect is important for anatomy educators across student populations because it can help determine when it is best to incorporate activities that develop student study strategies or other skills that are tangentially related to the course content. However, given the variance between and even within the allied health and medical student populations, it is critical for each anatomy educator to identify when their specific student population becomes less receptive to metacognitively monitoring and modifying their study strategies.

5.6 Educational Recommendations

5.6.1 Overarching Recommendations

Based on the insights gained from these three studies, several recommendations can be made to improve the metacognitive practices of both students and educators of the anatomical sciences, simultaneously. One possible method of supporting both populations is through an expansion of reflective writing. As noted in Sections 2.2.2 and 2.5, reflective writing in various forms can support the metacognitive development of both students and educators. Although the process of writing a critical reflection is typically meant to benefit the writer, the completed responses can also serve as valuable, naturalistic feedback for the educator who reviews them. For example, during data analysis, the process of critically reviewing student reflections from the Canvas discussion boards and PBLI assignments provided me, as an educator in both the D528 and Human Structure courses, with insights into how students were learning the material, including common strategies, resources, and struggle points. Reflection on these responses in turn can guide how I teach in these courses moving forward. Similarly, educators and course directors could also reflect on this naturalistic feedback to monitor their students' learning and evaluate the effectiveness of their teaching in lieu of formal assessments or course evaluations. Since these modifications are drawn directly from the students, the course becomes more learner-centered in the process as well. Although this example is anecdotal, there is evidence to support this mutually beneficial usage of student reflections (Rao et al., 2017). Therefore, reflective writing assignments can be mutually beneficial, not only promoting the metacognitive development of students, but also of educators if they are used as feedback for metacognitive reflection.

Metacognitive modeling can also support the metacognitive development of both students and educators simultaneously. In this method, the educator models their metacognitive processes for their students by explicitly verbalizing their thoughts and rationales as they teach (Wall and Hall, 2016). As a result, the students have an example upon which to scaffold their own metacognitive processes when they encounter a similar situation (Wilson and Bai, 2010; Wall and Hall, 2016). For example, during a dissection laboratory session in which students are struggling to locate a particular structure, rather than simply identifying the structure for the students, the educator can verbalize what landmarks or relationships they are searching for, what looks typical or atypical, and how they ultimately came to their final identification. Then, when the students must identify the structure independently, they have a greater awareness of what they need to consider as they dissect. This continuous verbalization also encourages open dialogue between student and educator, providing both parties with insight into what the other is thinking and centering the learners in the learning process (Wall and Hall, 2016). For educators, explaining their mental processes and identifying where student questions arise provides them with feedback they can use to monitor and evaluate both their teaching and student learning (Wilson and Bai, 2010). For students, understanding the rationale for different educational activities and assignments provides them with insight into the educator's intended goals, giving them concrete targets to plan and evaluate their learning around (Wilson and Bai, 2010; Wall and Hall, 2016). Therefore, metacognitive modeling presents a simple method for encouraging the metacognition of both students and educators with minimal need for additional teaching time or resources.

5.6.2 Student-Specific Recommendations

The metacognition of students learning anatomy can also be supported through several different avenues. First, student receptiveness to modifying their study strategies diminishes over time due to concurrent commitments competing for their time and energy. Educators should consider positioning activities early on in a course or program when students are most receptive to study modification. Frontloading activities towards the beginning of a course and steadily reducing their frequency would allow educators to capitalize on students' initial receptiveness and fully equip them with essential study skills while avoiding overburden later in the course, particularly when students are engaged in a course-heavy curriculum. However, the rate at which student receptiveness diminishes can vary between and even within student populations. Although early in the course is likely better, educators should consider their unique educational context and identify when their specific student population is most receptive to developing their metacognition and modifying their study strategies. Outside of discussion boards and/or reflective writing, many types of activities can be incorporated early to improve metacognition among students, such reflective exam wrapper assignments (Schuler and Chung, 2019), team-based learning (Martirosov et al., 2021), activities related to drawing and modeling of anatomical structures (Naug et al., 2011), and guidance specifically targeted at improving metacognition (e.g. encouraging monitoring and control of learning) (Stanton et al., 2021).

Given its association with top performing students and predictive accuracy in both the allied health and medical student populations, educators should also provide their students with opportunities to develop their declarative knowledge. Metacognitive knowledge, which includes declarative knowledge, serves as a foundation for other metacognitive processes such as monitoring exam preparedness. Declarative knowledge can be supported by providing students with ample information regarding examination format and expectations such as SMART (Specific, Measurable, Attainable, Relevant, and Time-Bound) learning objectives as well as practice quizzes or questions in a format similar to the actual examination (Chatterjee and Corral, 2017). This additional declarative knowledge and authentic opportunities to self-assess should allow students to judge their preparedness and predict their future performance more accurately. Moreover, providing students with guidance on how to use practice quizzes and questions to metacognitively self-assess knowledge and identify weaknesses would also help students predict their examination preparedness and future performance more accurately.

5.6.3 Educator-Specific Recommendations

Based on the findings of the third study, novice educators should be provided with multiple opportunities to reinforce their anatomical knowledge before and throughout the course in which they teach. Prior to the start of the course, teaching assistants should be provided with updated course materials (e.g., learning objectives, lecture slides and recordings, dissection guides, etc.) to allow them to self-study and refamiliarize themselves with the content. Tasking TAs with preparing a complete prosection for the course on a designated anatomical donor would also reinforce both their anatomical knowledge and dissection skills (Resuehr and Makeeva, 2015). These two recommendations should provide TAs with a solid review of the course material without overburdening the existing teaching team, although a more thorough review would be beneficial if time and resources allow.

More experienced anatomy educators can also be supported by providing them with professional development opportunities focusing on their unique interests. These opportunities could include workshops, seminars, or professional learning communities on topics such as diversity, equity, and inclusion (DEI), pedagogy, or communication.

Although these topics are not directly related to the core anatomy content, they encompass several relevant and important issues in both the anatomy community and medicine as a whole. Training educators in these topics can help them provide their students with a more socially-aware education that students can apply to their future careers.

5.7 Study Limitations and Future Directions

As with any research study, these studies are not without limitations and opportunities for further exploration.

5.7.1 Metacognition in Allied Health Students

One of the key limitations of this study was that the study population only included a single cohort of allied health students in a single gross anatomy course (D528) at a single institution (IUSM). As such, the results and conclusions obtained from this study may not be generalizable to other cohorts of allied health students or gross anatomy courses at other medical institutions. As mentioned in Section 3.1.3., the Metacognitive Awareness Inventory (MAI) is also limited in its ability to fully capture the nuances of an individual's metacognition due to its close-ended, dichotomous response system. Although students were forced to select from a binary set of responses, a more accurate representation of their metacognition may have existed somewhere between the dichotomous options. The metacognitive discussion boards were also limited in their data collection by both a non-response and courtesy biases. Since participation in the discussion boards was entirely optional, proactive students may have been more inclined to complete them compared to other students in the course. This limitation was exacerbated due to a steady decline in student response rate to the discussion boards as the course progressed. Since the students were aware that their responses would be publicly available to both the instructors and their peers in the course, they may have been more inclined to provide responses that along the lines of what they perceived the instructors would want to see or may have been less truthful about their difficulties to avoid embarrassment. Due to the COVID-19 pandemic and its associated restrictions, all elements of the D528 course were conducted virtually. This abrupt transition to an online curriculum forced students into a potentially unfamiliar educational environment, which may have impacted their ability to learn and practice metacognition. However, the timing of this study during the pandemic may have been greatly beneficial, as students were relying more heavily on their metacognitive skills (Anthonysamy, 2021). Furthermore, improvement in students' metacognition cannot be attributed to any one educational technique, but rather must consider other potential contributing factors. During the course, students participated in several activities known to improve metacognition such as team-based learning (TBL; Turan et al., 2009) and reflective writing (Alt and Raichel, 2020), both as part of this course, other concurrent courses, and independently. Therefore, mapping of such metacognitive activities should be considered by educators when implementing strategies to improve metacognition within their specific course.

Future work includes repeating this study with future cohorts of allied health students in a typical in-person, dissection-based gross anatomy curriculum, which would allow for comparison of student metacognition under both virtual and in-person conditions. There are intentions to expand the study into the undergraduate medical curriculum, it would be beneficial to extend this study longitudinally into later courses of the allied health curriculum to determine if and how student metacognition changes as they develop into full-fledged healthcare professionals.

5.7.2 Metacognition in First-Year Medical Students

Due to the COVID-19 pandemic and its associated restrictions, several elements of the Human Structure course were restructured and delivered virtually in 2020. This abrupt transition to an online curriculum forced students into a potentially unfamiliar educational environment, which may have impacted their ability to accurately monitor and evaluate their learning in their reflections. However, this study included data over a 5-year period, which would mitigate any influence online learning may have had on the data. Additionally, no themes were identified relating to online learning, indicating that such instruction did not influence students' perceptions of exam preparation. Data collection using the PBLI assignments also included several limitations. For one, since the students were aware that their responses would be critically reviewed by their course director, they may have experienced a courtesy bias and answered in a manner they thought would be pleasing to the course director rather than being completely honest about their study strategies. It's also possible that some students may have engaged in superficial reflection to complete the assignment rather than engaging in genuine critical reflection on their study strategies. Another key limitation of this study involves the demographics of the participating medical students. Due to the structural inequities present in the medical education system, students from backgrounds underrepresented in medicine (UiM) have been shown to consistently score lower on standardized assessments compared to their peers, causing them to struggle with and possibly even fail their coursework at higher rates than their peers (McDade et al., 2020). Since the socioeconomic backgrounds of the students were not readily available, this factor was not accounted for in the analyses. Therefore, it is possible that the disadvantages faced by UiM students may have negatively influenced their academic performance and metacognition and may have caused them to disproportionally represent the population of students who failed and repeated their coursework.

In the future, this study could be expanded longitudinally by exploring how the examination preparation strategies and metacognitive abilities of undergraduate medical students change across other key timepoints such as after the other examinations of the integrated anatomy course, across the other basic science courses of the medical curriculum, and after the transition into the clinical phase of their curriculum. An additional longitudinal study could also compare the metacognitive reflections of medical students across the pre-, mid-, and post-COVID years to determine if there are any significant differences. Lastly, future studies should focus on addressing known risk factors for course failure such as poor time management or inflexibility of study strategies.

5.7.3 Metacognition of Anatomy Educators

One of the key limitations of this study is that it was performed on education-focused at a single medical institution. As such, the results and conclusions gained may not be generalizable to educators at other institutions, particularly those who are more research-focused rather than teaching-focused. Interestingly, the population of participating educators was almost completely comprised of individuals who identified as female. Therefore, this study could not compare educators of different genders to determine if there were any significant differences in metacognition. The Teacher Metacognition inventory (TMI) is also limited in its ability to collect rich, nuanced data due to its close-ended Likert-scale response system. Another limitation of this study design is the variance in completion time for the post-teaching reflective journals. Due to myriad of potential reasons such as professional and personal commitments or simply forgetting, some educators did not complete their reflective journal entries in a consistent or timely manner. Calendar invites and weekly reminders emails were used to mitigate this issue, but it was not possible to guarantee consistent, prompt completion of the reflective journals. Given that human memory diminishes rapidly over time, this extended time between the teaching session and journal completion may have negatively impacted the accuracy of the educators' recall of events, causing them to forget or misrepresent some details (Inda et al., 2011). As a result, some reflective journal entries were not as detailed as others from the same individual. A future study could address this limitation by implementing a speak-aloud protocol in which the participant voices their thoughts in real-time as they perform a given task (Benton, 2013).

Future studies into the metacognition of anatomical sciences educators could also proceed in several different avenues. For one, future studies should focus on developing the metacognition of these educators, given the numerous potential benefits to both the educator themselves and their students. Additional studies could continue to follow these educators to determine if their metacognitive gains transfer to teaching other anatomical sciences (e.g., embryology, histology, or neuroanatomy) or the clinical setting as well. To better connect reflection and execution, a study could also employ direct, naturalistic observation methods of data collection in which the educators' teaching behaviors are observed and recorded in a real-world setting (Vonk et al., 2007). This approach could help determine if the educators indeed took concrete steps to modify their teaching practices as they intended based on their reflective journal responses.

5.7.4 Limitations to Cross-Study Comparisons

As noted in Section 3.4, several limitations prevent a direct comparison across the three study populations. First, the three studies each relied on a different quantitative data collection instrument, which resulted in the number and wording of question items, response options (e.g., dichotomous vs. Likert scale), timepoint of administration (e.g., pre- and post-course vs. pre- and post-exam), and intended purpose. Additionally, the qualitative data collection methods used in the studies varied in the number and wording of open-ended items, frequency and timepoint of administration, and intended purpose. The courses in which the studies occurred also differed in their content, student populations, and overall course structure. Collectively, these limitations prohibit direct comparisons and analyses across the three studies, though some trends could still be identified.

5.8 Conclusion

Metacognition is an essential skill for both students and educators of the anatomical sciences. The results derived from these studies provide several key insights into how, when, and why these populations engage in metacognition. Allied health students were found to improve their metacognition across a semester of dissection-based gross anatomy. However, the willingness of the students to practice that metacognition diminished over time as other concurrent academic and professional competed for their limited time and energy. By the end of the course, the allied health students were more likely to "double down" on a familiar, but potentially less effective strategy rather than continue exploring other potentially more effective strategies. As such, educators who are interested in developing the metacognitive and study strategy skills of their students should frontload these activities towards the beginning of the course when students are most receptive.

Retrospective analysis of five years of pre- and post-examination reflections showed that undergraduate medical students were able to predict their examination performance with moderate accuracy. Similar to their allied health peers, medical students also became less receptive to modifying their study strategies over time and likely relied on declarative knowledge to self-assess their learning. Medical students who initially failed and repeated their course preferred to enhance existing study strategies, manage their time more effectively, and use the anatomy laboratory and practice questions more effectively on their second attempt. Conversely, top performing students were more metacognitive and more adaptive, but only until they identified a strategy they deemed successful. These results highlight key differences between how top performing and repeating students and characteristics of struggling students at risk of failing anatomy, making it easier for educators to identify and support these students prior to course failure.

Exploration of the metacognition of anatomy educators revealed several interesting findings with significant implications. As a whole, the educators improved their metacognition across a semester of teaching gross anatomy, particularly in their reflective ability and their personal awareness of their own strengths and weaknesses as educators. When compared to the faculty and associate instructors, teaching assistants exhibited the most pronounced metacognitive growth, possibly because they were in a formative period of their development as educators. In the post-teaching reflective journals, novice instructors such as the TAs were more self-critical, teacher-centered, fixated on their own content mastery. Conversely, experienced instructors such as faculty and AIs were less self-critical, more learner-centered, and fixated on a variety of additional factors that impacted student learning. These key findings are important in guiding how to best support the professional development of anatomy educators at different stages in their careers.

However, as noted previously in this dissertation, the identification of areas of improvement is meaningless without subsequent action to address those areas. Now that the results of these studies have shed light on how both students and educators engage in metacognition in the anatomical sciences, these insights need to be applied towards improving the metacognition of these groups. Although “thinking about thinking” will always remain essential, we as anatomical sciences educators must now think about action, and identify clear, concrete methods for improving our metacognition and the metacognition of our students.

APPENDICES

Appendix A. Metacognitive Awareness Inventory (MAI)

Introduction Message

Metacognitive Awareness Inventory (ANAT D528)

Thank you for your interest in participating in this research study of student metacognition in a gross anatomy course for healthcare professionals. We greatly appreciate your time and effort in completing this survey! The survey results will be used for research purposes, but will also be provided to you to help you identify and improve some of the strengths and weaknesses of your study practices.

Participation in this educational research study is completely voluntary and will require roughly 7 minutes to complete. You may cease participation at any time without any consequences. All survey results will be kept confidential (including from your course director and peers) and will not impact your course grade. The risks associated with this study are minimal and no greater than those typically encountered in a classroom setting. By proceeding to the survey, you are affirming that you are over the age of 18 and providing consent to participate in this research study.

If you have any questions or concerns, please feel free to contact:

Andrew Cale, MS: ascale@iu.edu
Dr. Margaret McNulty, PhD (PI): mcnultma@iu.edu

Indiana University is the responsible institutional review board (Protocol #2004367557); please contact IU-IRB at (317) 274-8289 with any questions or concerns regarding this educational study.

Demographics

Please enter the initials of your first and last name followed by your birth month and day.

E.g. John Doe born January 24 would be "JD0124"

This unique code will be used to correlate your individual pre- and post-surveys and will not be shared.

What is your age?

What is your self-identified gender?

- ◯ Female
- ◯ Male
- ◯ Other
- ◯ Prefer not to say

What is your program of study?

- ◯ Physician Assistant (PA)
- ◯ Physical Therapy (PT)
- ◯ Occupational Therapy (OT)
- ◯ Other

What is the highest level of education you have completed?

- ◯ Bachelor's degree (e.g. BA, BS)

◯ Master's degree (e.g. MA, MS)
◯ Doctoral degree (e.g. PhD, EdD)
◯ Professional degree (e.g. RN, MD, DVM)

Metacognitive Awareness Inventory

Think of yourself as a learner. Read each statement carefully. Consider if the statement is true or false as it generally applies to you when you are in the role of a learner (student, attending classes, university etc.)

I understand my intellectual strengths and weaknesses.

◯ True
◯ False

I know what kind of information is most important to learn.

◯ True
◯ False

I am good at organizing information.

◯ True
◯ False

I know what the teacher expects me to learn.

◯ True
◯ False

I am good at remembering information.

◯ True
◯ False

I have control over how well I learn.

◯ True
◯ False

I am a good judge of how well I understand something.

◯ True
◯ False

I learn more when I am interested in the topic.

◯ True
◯ False

I try to use strategies that have worked in the past.

◯ True
◯ False

I have a specific purpose for each strategy I use.

◯ True
◯ False

I am aware of what strategies I use when I study.

- ◯ True
- ◯ False

I find myself using helpful learning strategies automatically.

- ◯ True
- ◯ False

I learn best when I know something about the topic.

- ◯ True
- ◯ False

I use different learning strategies depending on the situation.

- ◯ True
- ◯ False

I can motivate myself to learn when I need to.

- ◯ True
- ◯ False

I use my intellectual strengths to compensate for my weaknesses.

- ◯ True
- ◯ False

I know when each strategy I use I use will be most effective.

◯ True
◯ False

I pace myself while learning in order to have enough time.

◯ True
◯ False

I think about what I really need to learn before I begin a task.

◯ True
◯ False

I set specific goals before I begin a task.

◯ True
◯ False

I ask myself questions about the material before I begin.

◯ True
◯ False

I think of several ways to solve a problem and choose the best one.

◯ True
◯ False

I read instructions carefully before I begin a task.

- ◯ True
- ◯ False

I organize my time to best accomplish my goals.

- ◯ True
- ◯ False

I slow down when I encounter important information.

- ◯ True
- ◯ False

I consciously focus my attention on important information.

- ◯ True
- ◯ False

I focus on the meaning and significance of new information.

- ◯ True
- ◯ False

I create my own examples to make information more meaningful.

- ◯ True
- ◯ False

I draw pictures or diagrams to help me understand while learning.

- ◯ True
- ◯ False

I try to translate new information into my own words.

- ◯ True
- ◯ False

I use the organizational structure of the text to help me learn.

- ◯ True
- ◯ False

I ask myself if what I’m reading is related to what I already know.

- ◯ True
- ◯ False

I try to break studying down into smaller steps.

- ◯ True
- ◯ False

I focus on overall meaning rather than specifics.

- ◯ True
- ◯ False

I ask myself periodically if I am meeting my goals.

- ◯ True
- ◯ False

I consider several alternatives to a problem before I answer.

- ◯ True
- ◯ False

I ask myself if I have considered all options when solving a problem.

- ◯ True
- ◯ False

I periodically review to help me understand important relationships.

- ◯ True
- ◯ False

I find myself analyzing the usefulness of strategies while I study.

- ◯ True
- ◯ False

I find myself pausing regularly to check my comprehension.

- ◯ True
- ◯ False

I ask myself questions about how well I am doing while learning something new.

- ◯ True
- ◯ False

I ask others for help when I don't understand something.

- ◯ True
- ◯ False

I change strategies when I fail to understand.

- ◯ True
- ◯ False

I re-evaluate my assumptions when I get confused.

- ◯ True
- ◯ False

I stop and go back over new information that is not clear.

- ◯ True
- ◯ False

I stop and reread when I get confused.

- ◯ True
- ◯ False

I know how well I did once I finish a test.

◯ True
◯ False

I ask myself if there was an easier way to do things after I finish a task.

◯ True
◯ False

I summarize what I've learned after I finish.

◯ True
◯ False

I ask myself how well I accomplish my goals once I'm finished.

◯ True
◯ False

I ask myself if I have considered all options after I solve a problem.

◯ True
◯ False

I ask myself if I learned as much as I could have once I finish a task.

◯ True
◯ False

Appendix B. ANAT D528 Metacognitive Discussion Board Prompts

Title	Prompt
Best Study Strategies	Every year, students ask "what's the best way to study anatomy?" But first, how do you study *overall*? Do you feel this strategy will be effective for this anatomy course? What can you do to improve your study strategy?
Monitoring Learning	How have you been monitoring your progress as you study? How do you know you've "learned" the material?
Exam 1 Reflection	Reflect on your exam performance. What types of questions did you tend to miss? What types of errors did tend you to make? What can you do to avoid those errors in your future exams?
Exam 2 Reflection	Reflect on your past exam performances. What types of questions did you tend to miss? What types of errors did tend you to make? What can you do to avoid those errors in your future exams? Is this the same or different from Exam 1?
Anatomy Learning	Why do you think anatomy is hard or easy to learn? If you think it is challenging, what can you do to make the process easier?
Exam 3 Reflection	Reflect on your past exam performances. What types of questions did you tend to miss? What types of errors did tend you to make? What can you do to avoid those errors in your future exams? Is this the same or different from previous exams?
Study Strategy Reflection	Reflect on the different study strategies you used this semester. Which strategies were most or least effective for you? How will you use these strategies in your future courses?
Advice for Future Students	What advice would you give to future students taking anatomy?

Appendix C. HS Practice-Based Learning and Improvement Assignments

This combined PBLI1/SDL reflective exercise guides you to engage in the four elements of self-directed learning by prompting you to reflect on your strengths and potential limitations, to use this information to close gaps in your understanding, to consider and weigh quality or usefulness of learning resources, and to share this with others (Part I). As you continue in your preparation for the first exam, you have the opportunity to assess your level of confidence of a favorable outcome and to reflect on the effectiveness of laboratory and peer interactions and their contributions to your learning in the anatomy/histology laboratories.

1. With respect to the upcoming Block 1 Exam, identify the two areas/topics in which you feel <u>best</u> prepared.
2. With respect to the upcoming Block 1 Exam, identify the two areas/topics in which you feel <u>least</u> prepared.
3. How did you determine what you needed to learn for this exam? How did you go about addressing your learning needs?
4. Which resources have you found to be most helpful for addressing your learning needs? Which have been least helpful?

(Highlight your selected choice for questions 5-7)

5. How confident do you feel about performing well on the first exam? (Highlight your selected choice below)

[Not confident at all --- Low confidence --- Moderate confidence --- High confidence --- Certain]

6. What % score are you aiming to achieve on the upcoming exam?

[92-100% --- 85-91% --- 70-84% --- <70%]

7. In what ways has the laboratory process and interaction with your peers impacted your learning? (Select all that apply)

[Made me feel more accountable to peers --- Helped reinforce what I was learning in lecture – Working with others made my studying more efficient --- Other]

PBLI1 Part 2 template

Part 2 of this combined PBLI1/SDL reflective exercise asks you to confirm whether your confidence going into the first exam was accurate and realistic, and whether your performance goals were achieved. This information will be helpful to both you and faculty instructors in considering any revisions that may need to be made in study strategies for either component of the course in advance of the second exam. Because this assessment comes just before the middle of the second block you should have time to implement new strategies before the second exam. Continued practice and implementation of these skills will increase your confidence as an autonomous learner. These are foundational elements in your development as a life-long learner.

1. Were you satisfied with your performance on Exam 1?

   Yes No Not Sure

2. Reflecting on your approach to learning the material for Block 1 and your score, what approaches will you preserve in your approach to Block 2 and what approaches will you modify or eliminate?

3. Going forward, how will you decide what resources to rely on to most effectively learn anatomy?

Appendix D. Teacher Metacognition Inventory (TMI)

Survey Information

Thank you for your interest in participating in this research study on educator metacognition. We greatly appreciate your time and effort in completing this survey! The survey results will be used for research purposes, but will also be provided to you to help you enhance your educational practices as a teacher.

Participation in this educational research study is completely voluntary and will require roughly 10 minutes to complete. You may cease participation at any time without any consequences. All survey results will be kept confidential and will not impact your academic or professional standing in any way. The risks associated with this study are minimal and no greater than those typically encountered in a classroom setting. By proceeding to the survey, you are affirming that you are over the age of 18 and providing consent to participate in this research study.

If you have any questions or concerns, please feel free to contact:
Andrew Cale, MS: ascale@iu.edu
Dr. Margaret McNulty, PhD (PI): mcnultma@iu.edu

Indiana University is the responsible institutional review board (Protocol #11231); please contact IU-IRB at (317) 274-8289 with any questions or concerns regarding this educational study.

Do you consent to participating in this survey on educator metacognition?

- ◯ Yes, I agree to participate in this study
- ◯ No, I do not wish to participate in this study

Demographic Information

Please type in your Indiana University CAS username below:

____

***NOTE:** This information will only be used to connect your individual pre- and post-surveys. Your identifier and your responses will not be shared with the course director, department chair, or any other faculty members and will not affect your course grades and/or academic/professional standing in any way.

What is your age?

____

What is your self identifier?

- ◯ Man
- ◯ Woman
- ◯ Prefer not to say
- ◯ Other

Please specify:

____

What is your current academic title?

____

Do you have any previous teaching experience?

- ◯ Yes
- ◯ No

If yes, how many years of teaching experience do you have?

- ◯ Less than 1 year
- ◯ 1-3 years
- ◯ 4-6 years

◯ 7+ years

What is the highest level of education that you have completed?

◯ Bachelor's degree
◯ Master's degree
◯ Doctoral degree
◯ Professional degree

Teacher Metacognitive Experience

Please indicate whether you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I am worried when my students feel bored in my class.	◯	◯	◯	◯	◯
I am worried when I am unable to control the pace of my lesson well.	◯	◯	◯	◯	◯
I feel anxious when I encounter problems in my teaching.	◯	◯	◯	◯	◯
I feel relaxed when I complete my teaching tasks.	◯	◯	◯	◯	◯
I feel happy when I created a good lesson plan.	◯	◯	◯	◯	◯

Metacognitive Knowledge about Pedagogy

Please indicate whether you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I know demonstration can make abstract concepts more concrete in learning.	◯	◯	◯	◯	◯
I believe questioning techniques can stimulate students' thinking.	◯	◯	◯	◯	◯
I understand that small group discussion is not suitable when lesson time is tight.	◯	◯	◯	◯	◯
I believe interacting with students helps them to be more attentive in class.	◯	◯	◯	◯	◯

Teacher Metacognitive Reflection

Please indicate whether you agree or disagree with the following statments:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I assess the appropriateness of the learning objectives after I taught the class.	◯	◯	◯	◯	◯

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I reflect on the lesson design after each lesson.	◯	◯	◯	◯	◯
I reflect on how well I meet the lesson objectives after each lesson.	◯	◯	◯	◯	◯
I think about whether there are alternative teaching strategies after teaching a class.	◯	◯	◯	◯	◯
I reflect on the effectiveness of a lesson after the class.	◯	◯	◯	◯	◯
I reflect on my teaching after the lesson.	◯	◯	◯	◯	◯
I evaluate the extent to which I have achieved the lesson objectives after a class.	◯	◯	◯	◯	◯

Metacognitive Knowledge about Self

Please indicate whether you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I have a good grasp of the concept, principles, and methods of the subject(s) I teach.	◯	◯	◯	◯	◯
I am able to prepare myself before the start of a class.	◯	◯	◯	◯	◯
I know the strengths in my teaching.	◯	◯	◯	◯	◯
I am aware of my shortcomings in my teaching.	◯	◯	◯	◯	◯

Teacher Metacognitive Planning

Please indicate whether you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I predict and plan for possible classroom scenarios.	◯	◯	◯	◯	◯
I set clear learning goals before each class.	◯	◯	◯	◯	◯
I prepare and plan my lesson before teaching a class.	◯	◯	◯	◯	◯

Teacher Metacognitive Monitoring

Please indicate whether you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I pay attention to the state of my emotions when I teach.	◯	◯	◯	◯	◯
When teaching, I frequently check whether the progress of the lesson is as planend.	◯	◯	◯	◯	◯
When teaching, I often ask myself "how well do I teach?"	◯	◯	◯	◯	◯
I constantly assess the feasibility of the teaching strategies I use when in class.	◯	◯	◯	◯	◯
I constantly check students' understanding of the lesson.	◯	◯	◯	◯	◯

Appendix E. ANAT D528 Post-Teaching Reflections

1. Overall, how did you feel prior to, during, and immediately after your most recent teaching session?

2. What do you believe you did well as an instructor in your most recent teaching session? What evidence can you identify that would support this claim?

3. What do you believe you could have done better as an instructor in your most recent teaching session? What evidence can you identify that would support this claim?

4. What are your plans for your next teaching session? Which educational practices will you continue using, modify, or abandon? Why?

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CURRICULUM VITAE

Andrew Stephen Cale

Education

PhD Anatomy, Cell Biology, and Physiology (Education Track) 2023
Education and Communicating Science Minors
Indiana University – Indianapolis

MS Modern Human Anatomy (MHA) 2018
Certificate in Anatomical Sciences Education
University of Colorado Anschutz Medical Campus

BS Neurobiology, Physiology, and Behavior 2013
University of California, Davis

Academic Appointments

Associate Instructor – PhD Student 8/2019 – 6/2023
Indiana University School of Medicine – Indianapolis

Adjunct Instructor 7/2018 – 12/2018
Regis University, Rueckert-Hartman College for Health Professions

Awards and Recognitions

2023 IU Lieber Memorial Associate Instructor Award

2022 AAA Student/Postdoctoral Education Research Poster Award
IUPUI Graduate and Professional Education Travel Grant
IUSM Graduate Student Travel Award

2021 IUPUI Sherry Queener Graduate Student Excellence Award (nominee)
IU David B. Burr Educational Fellowship in Anatomical Education

2019 IUSM Graduate Student Travel Award
IUPUI Graduate and Professional Education Travel Grant

2018 MHA Excellence in Teaching Award
MHA Excellence in Service Award (nominee)

Teaching

Teaching Experiences

Indiana University School of Medicine – Indianapolis
- MEDX 620 Human Structure 2020, 2022
- ANAT D528 Gross Anatomy for Healthcare Professionals 2020-2022
- ANAT D502 Basic Histology 2021
- MEDX 660 Neuroscience and Behavior 2021
- ANAT D527 Neuroanatomy: Contemporary and Translational 2021
- MEDX 755 Endocrine, Reproduction, Musculoskeletal and Dermatology 2021
- ANAT D501 Human Gross Anatomy 2020

Regis University
- HES 374 Applied Human Anatomy 2019

University of Colorado Anschutz Medical Campus
- DPTR 5001 Clinical Anatomy I 2019
- ANAT 6111/ANMS 5007 Human Gross Anatomy 2018
- Human Body Block 2017

University of California, Davis
- CHA 101L Human Gross Anatomy 2014-2016

Continuing Education
- ANESTH Cadaver Review Session (IUSM) 2021-Present
- Teaching, Learning, and Professor Support for Graduate TAs 2021-2022
- ANAT D528 Gross Anatomy Make-Up Labs 2021
- ANESTH Cadaver Review Session (CU-AMC) 2017-2019

K-12 and Public Outreach
- Anatomy Nights 2019-Present
- IU Center for Anatomy and Physiology Education Lab Tours 2019-Present
- Taste of Science Indianapolis 2021
- 18th Annual Health Professions Consortium 2019
- Community Brain Expo Day 2019
- Wellness, Lifelong, and Career Orientation Mentoring 2017-2019
- Brain Awareness Week 2017-2018
- CO-Area Health Education Center Obesity Outreach Project 2017-2018
- Camp Neuro 2017

Enduring Instructional and Curriculum Materials
- Anatomy Catch-Phrase Game (Primary Developer)
- Active Lesson Digital Dissection Manual (Image Annotator)

- Anesthesiology Acute Pain Service Gross Anatomy Review Module (Primary Developer
- Metacognition-Based Active Learning Review Session (Primary Developer)

Research

Refereed Publications

Cale AS, Byram JN, Organ JM, Schmalz NA. (2022). "A Whole New Perspective on How the Body Fits Together" - An Evaluation of a Cadaver Laboratory Experience for High School and Undergraduate Students. Anat Sci Educ. ***Accepted** *(October 2022)**

Cale AS, Hoffman LA, McNulty MA. (2022). Promoting metacognition in an allied health anatomy course. Anat Sci Educ. 00:1-13. https://doi.org/10.1002/ase.2218

Sanders KA, Philp JAC, Jordan CY, **Cale AS**, Cunningham CL, Organ JM. (2022) Anatomy Nights: An international public engagement event increases audience knowledge of brain anatomy. PLOS ONE 17(6): e0267550. https://doi.org/10.1371/journal.pone.0267550

Cale AS, Hendrickse A, Lyman M, Royer DF. (2020). Integrating a Cadaver Review Session into the Existing Regional Anesthesia Training for Anesthesiology Residents: An Initial Experience. Med Sci Educ. 20:695-703.

Conference Presentations

2022 **Cale AS**, McNulty MA. An Exploration of Metacognitive Practices in Gross Anatomy Educators. Philadelphia, PA, USA. The FASEB Journal, 36:S1.R2386.
*Finalist and Winner; AAA/Anatomical Sciences Education Journal Student/Postdoc Education Research Poster Presentation Award
**Poster presentation at AAA Annual Meeting (Philadelphia, PA)

Cale AS, McNulty MA, Hoffman LA. Learning from the Past: A Five-Year Analysis of the Exam Preparations of Students Repeating an Integrated Medical Anatomy Course. The FASEB Journal, 36:S1.R2467.
*Selected as one of 10 AAA posters to be featured during the Experimental Biology opening reception.
**Poster presentation at AAA Annual Meeting (Philadelphia, PA)

Cale AS, McNulty MA, Hoffman LA. Expectation Rarely Matches Reality: A Five-Year Analysis of Anatomy Exam Score Predictions by First-Year Medical Students.
**Poster presentation at IUSM Education Day (Indianapolis, IN)
**Poster presentation at AAA Regional Meeting (Virtual)

2021 **Cale AS**, McNulty MA. Realistic Implementation of Metacognitive Activities in an Allied Health Anatomy Course. The FASEB Journal, 35:S1.01726.
*Finalist and Runner-Up; AAA/Anatomical Sciences Education Journal Student/Postdoc Education Research Poster Presentation Award
**Poster presentation at AAA Annual Meeting (Virtual)
**Poster presentation at IUSM Education Day (Virtual)

Cale AS, McNulty MA. Metacognition in the Middle: Mismatch between Anticipated and Actual Exam Grades of Allied Health Anatomy Students. The FASEB Journal, 35:S1.01742.
**Oral presentation at AAA Annual Meeting (Virtual)
**Poster presentation at IUSM Education Day (Virtual)

2020 **Cale AS**, Byram J, Schmalz N. "A Whole New Perspective on How the Body Fits Together" – An Evaluation of a Cadaver Lab Experience for High School and Undergraduate Students. The FASEB Journal, 34:S1.03306.
**Poster presentation at AAA Annual Meeting (Virtual)
**Poster presentation at IUSM Education Day (Indianapolis, IN)

Cale AS, Lee LMJ. Those Who Can't Do, Teach Anatomy? The Presence of Stereotype Threat in Anatomical Sciences Educators. The FASEB Journal, 34:S1.02344.
**Poster presentation at AAA Annual Meeting (Virtual)

2018 **Cale AS**, Hendrickse A, Lyman M, Royer D. Gross Anatomy Review for Anesthesiology Residents on the Acute Pain Service: How Basic Science Training Could Improve Knowledge and Confidence. The FASEB Journal, 32:504.9-504.9.
**Poster presentation at MHA Capstone Presentations (Denver, CO)
**Poster presentation at AAA Annual Meeting (San Diego, CA)
**Poster presentation at AAMC Western Group on Educational Affairs Regional Meeting (Denver, CO)
**Oral presentation at CU Education Scholarship and Innovation Symposium (Denver, CO)

Media Appearances

2022 IUPUI Community for Open Research and Education. Science Communication and Open Scholarship [Webinar]. In IUPUI Community for Open Research and Education Panel Series. https://ulib.iupui.edu/news/open-research-ed-2022

American Association for Anatomy. Student Seminar: Apply to Graduate Programs in Anatomy [Webinar]. In AAA Anatomy Webinar Series. https://anatomy.org/AAA/Meetings-Events/Event_display.aspx?EventKey=GRADSCHOOL

American Society for Microbiology. How to Make Your Mark on the Association [Webinar]. In Annual Biomedical Research Conference for Minoritized Students (ABRCMS) ePoster Spring Symposium for Emerging Scientists.

2021 American Association for Anatomy. Student Seminar: How to Make Your Mark on the Association [Webinar]. In AAA Anatomy Webinar Series. https://anatomy.org/AAA/Resources/Webinars-Folder/090921.aspx

2020 Pickering J. (Host). Lockdown Special X (Ep. 111) [Audio podcast episode]. In Anatomy Education Podcast. http://anatomypodcast.co.uk/episodes/lockdown-special-x/

Pickering J. (Host). Lockdown Special IX (Ep. 109) [Audio podcast episode]. In Anatomy Education Podcast. http://anatomypodcast.co.uk/episodes/lockdown-special-ix/

University, Professional, and Community Service

Professional Memberships

- American Association for Anatomy (AAA)
- American Association of Clinical Anatomists (AACA)
- International Association for Medical Science Educators (IAMSE)
- Human Anatomy and Physiology Society (HAPS)
- American Association for the Advancement of Science (AAAS)

Professional Service

- American Association for Anatomy (AAA)
  - Board of Directors (Student/Postdoc Director)
    - Membership Task Force
  - Ambassador Committee
    - Social Media Subcommittee
    - Events Subcommittee

University Service

- Master's in Modern Human Anatomy - Alumni Association (MHA-AA)
  - Networking Coordinator
- Taste of Science Indianapolis Planning Committee
- Student Outreach Community at IUSM (SOCI)
  - Treasurer

Non-Academic Publications

Cale, AS. (2022). On the Shoulders of Giants: One Scientist's Diabetes Research Journey. PLOS SciComm Blog. https://scicomm.plos.org/2022/05/03/on-the-shoulders-of-giants-one-scientists-diabetes-research-journey/

Cale, AS. (2020). Homeostasis at Home: 3(ish) Tips for Maintaining Your Optimal Work-Life Balance. The Plexus Post – A Newsletter from the Modern Human Anatomy-Alumni Association, 2(1). https://medschool.cuanschutz.edu/docs/librariesprovider157/default-document-library/the-plexus-post-oct-2020.pdf?sfvrsn=fa6a9fb9_2

Cale, AS. (2020). Confluence of Scientists: Five Tips for Your Next Scientific Conference. The Plexus Post – A Newsletter from the Modern Human Anatomy-Alumni Association, 1(2). https://medschool.cuanschutz.edu/docs/librariesprovider157/default-document-library/the-plexus-post-jan-20200e41fbe5302864d9a5bfff0a001ce385.pdf?sfvrsn=c1699fb9_2

Cale, AS. (2020). Synaptogenesis: Five Tips for Making New Networking Connections. The Plexus Post – A Newsletter from the Modern Human Anatomy-Alumni Association. 1(1). https://medschool.cuanschutz.edu/docs/librariesprovider157/default-document-library/the-plexus-post-sept-2019.pdf?sfvrsn=e0d78db9_2

Professional Development and Skills

Workshops, Trainings, and Courses

2022 Teaching Foundations: Teaching Metacognitive Skills
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

Teaching Foundations: Using Formative Assessment to Check Students' Learning
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

Improving Course Accessibility: Create Inclusive Documents with Seven Simple Steps
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

Teaching Foundations: Designing your Course for Equity and Inclusion
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

Teaching Foundations: Inclusive Teaching Strategies
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

Emerging Scholars of College Instruction Program (2021 cohort)
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

2021 MSCI M620: Pedagogical Methods in the Health Sciences
Indiana University School of Medicine

Zoom and Top Hat for Interactive Meetings and Course Delivery
Educational Technology, Indiana University School of Medicine

An Introduction to Mixed Methods for Social Scientists
Academy of Teaching Scholars, Indiana University School of Medicine

Teaching@IUPUI: Writing a Teaching Philosophy/Statement
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

2020 Teaching Portfolio Guide for Graduate Students and Postdocs
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

Zoom Alchemy: Active Learning in the Virtual Classroom
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

Grad Students and Postdocs: Making the Most of Guest Lecturing Experiences
Center for Teaching and Learning, Indiana University-Purdue University, Indianapolis

2018 ANAT 6490: Advanced Teaching in the Anatomical Sciences
Modern Human Anatomy Program, University of Colorado Anschutz Medical Campus

Conflict Management Skills Workshop
Ombuds Office, University of Colorado Anschutz Medical Campus