Received: 2 September 2021 | Revised: 9 August 2022 | Accepted: 9 August 2022

DOI: 10.1002/ase.2218

RESEARCH REPORT

Anatomical Sciences Education | AMERICAN ASSOCIATION FOR ANATOMY | WILEY

Promoting metacognition in an allied health anatomy course

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Abstract

Metacognition, the ability to self-regulate one's learning and performance, has been shown to improve student outcomes. Anatomy is recognized as one of the toughest courses in allied health curricula, and students could benefit from metacognitive activities. The purpose of this study was to explore the changes in metacognition of allied health students in an anatomy course and identify which groups need support with this skill. First-year physician assistant (MPAS), physical therapy (DPT), and occupational therapy (OTD) students ($n = 129$) were invited to participate. At the beginning and end of the course, students completed a questionnaire including the metacognitive awareness inventory (MAI) that assesses metacognition. Students were also asked to reflect on their examination performances using a modified Likert scale and participated in reflective discussion boards to encourage development of metacognitive skills, which were thematically analyzed. Paired metacognition scores had increased significantly by the end of the course. However, middle-performers anticipated high grades and were less satisfied with their grade, indicating a disconnect in their metacognition compared to high- and low-performers. Students' receptiveness to modifying study strategies to improve performance declined throughout the course; by mid-way through, they relied more on existing strategies. Increasing time constraints were frequently cited as a major factor when considering study strategies and modification of such strategies. To maximize the effectiveness of metacognitive activities, they should be positioned early in the course when students are most receptive. In addition, middle performers may benefit from additional support to improve metacognition.

KEYWORDS

allied health education, gross anatomy education, health professions education, metacognition, undergraduate education

INTRODUCTION

Metacognition, or “thinking about thinking”, is a powerful skill that can provide both students and healthcare professionals with a greater awareness of their own strengths and weaknesses. More specifically, metacognition is defined as the ability to plan, monitor, and evaluate one's own learning and performance (Medina et al., 2017). Since its initial description by John Flavell (1985) in the context of the development of young children, the literature on metacognition has expanded significantly, with applications in a variety of different populations and disciplines.

In the context of education, metacognition can improve the ability of students to think critically (Naimnule & 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 examinations, 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).

Furthermore, the significance of metacognition in medical education cannot be overstated. Metacognitive skills play such a critical role in clinician training that they are often incorporated into the standardized learning outcomes for trainee physicians (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 & 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 also linked these metacognitive skills to improved educational outcomes in medical education. For example, undergraduate 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 (Siqueira et al., 2020). Allied health students in a gross anatomy course also performed better on assessments after engaging in a metacognitive "blank page" challenge (Naug et al., 2016). In this activity, students are given a blank paper (or other medium devoid of visual cues) and asked to create a visual representation of a particular topic by actively recalling their knowledge. This engages students in experiential learning and encourages them to reflect and identify gaps in their knowledge when they are unable to independently recall their knowledge. An increase in students' metacognitive skills has also been linked to improved performance on standardized progress assessments (Chang et al., 2021).

Once healthcare 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, a Canadian physician 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). Well-developed metacognitive skills can help healthcare professionals adapt to these unpredictable changes more readily. 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 & 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 and colleagues surgeons attributed surgical errors to a failure to maintain metacognitive self-monitoring throughout the surgical procedure (Moulton et al., 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.

One possible method for explicitly introducing metacognitive development into the curriculum is through reflective writing. Low-stakes writing assignments can provide students with a method in which they can 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 & 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 & Raichel, 2020). In a study by Trujillo and colleagues, 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-examination assignments that asked students to reflect on their study strategies and build a study plan for future examinations were also shown to engage students in metacognition and guide their study practices (Stanton et al., 2021). In another study with undergraduate biology students, post-examination assignments that required students to correct and explain their own examination errors also encouraged the development of metacognitive skills (Mynlieff et al., 2014).

Asynchronous online discussion boards are a 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. 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 & 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 & 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.

The COVID-19 pandemic has profoundly changed the education landscape, 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 (Harmon et al., 2021; Attardi et al., 2022) and resulting impacts on students' learning (Pather et al., 2020; Owolabi & 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.

This study was designed with three research questions in mind: (1) How does the metacognition of allied health students change as they progress through a graduate-level anatomy course, (2) what are the relationships between student metacognition and other academic factors such as examination performance and program of study, and (3) how does participation in online reflective discussion boards impact the metacognition and academic performance of allied health students? Due to the use of an inductive approach and qualitative methods, a priori hypotheses are not given. Instead, the goal of the qualitative aspect of this study was to gain insight from allied health students of their perceptions regarding how they learned anatomy and whether these perceptions displayed metacognitive characteristics. As a concurrent triangulation mixed methods study, both the quantitative and qualitative elements were analyzed independently at first and then interpreted in tandem with one another to achieve a more holistic understanding (Creswell, 2009). The results of this study will provide insight into the metacognitive processes of allied health students and contribute to the existing literature regarding the impact of reflective discussion boards on student metacognition.

MATERIALS AND METHODS

Study overview and participant recruitment

This study was approved by the Indiana University (IU) Institutional Review Board (IRB) (Protocols #1804885093, 2004367557). First-year students enrolled in the Doctor of Physical Therapy (DPT; $n = 45$), Masters of Physician Assistant Studies (MPAS; $n = 46$), and Doctor of Occupational Therapy (OTD; $n = 38$) 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". Students were invited to complete a metacognition awareness survey 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.

Course description: Anatomy for healthcare professionals

Course overview

The anatomy course in which this study took place, "Anatomy for Healthcare Professionals" is a five-credit hour (approximately 43 h of lectures and 85 h of virtual laboratories), graduate-level interprofessional anatomy course designed to introduce students to the basic concepts and structures of the human body and was the first course of their professional curriculum. Students progressed through the anatomy of the human in a dissection-based curriculum, with the exception of the Summer 2020 iteration when students were taught virtually as described below. 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.

This course followed a regional approach, starting with the back, into the upper limb, then progressing through the thorax, abdomen, pelvis, and lower limb before finishing with the neck and head. Summative assessments were administered following the completion of four course blocks: (1) back and upper limb, (2) thorax and abdomen, (3) pelvis and lower limb, and (4) head and neck. Assessments were conducted online using Examplify platform (ExamSoft Worldwide, Inc., Dallas, TX) and 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).

Class sessions

Due to the COVID-19 pandemic, all course components of the Summer 2020 iteration were delivered virtually. Lectures were pre-recorded and delivered asynchronously through the institution's Canvas LMS learning management system (Thoma Bravo LLC., Chicago, IL). Virtual laboratory sessions were conducted synchronously using Zoom videoconferencing platform (Zoom Video Communications, Inc., San Jose, CA), using breakout rooms for small group work. The 129 students enrolled in the course were assigned to interprofessional laboratory groups (n = 6 students/group, 21 groups total) with approximately two students from each program in a group. During the virtual laboratory sessions, each group was placed in their own breakout room and students learned the anatomy virtually through completion of worksheets designed by the course director, consisting of short answer and identification questions on illustrations, radiographs, and cadaveric images to reinforce concepts encountered in lecture. Meanwhile, instructors (n = 4 faculty, 2 graduate [Ph.D.] students, and 3 teaching assistants) visited breakout rooms to answer questions. Despite being conducted virtually, the content in the course was the same as previous iterations. Additionally, the written assessments were identical to the assessments utilized in the course pre-pandemic. Resources that were recommended to the students included textbooks (Tank, 2013; Moore et al., 2017) and lecture material created by the course instructors.

Metacognitive discussion boards

To encourage the development of metacognitive awareness and skills among the students, a series of voluntary discussion prompts were deployed each week on Canvas, which are outlined in detail in Table 1. In these prompts, students were asked to practice metacognitive principles and reflect on specific aspects of their learning such as study strategies and examination performances. All discussion board 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 and learn from their peers. This approach encouraged independent reflection and reduced the likelihood that a student's reflection would be influenced by social comparison with their peers (Raat et al., 2013). 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.

Research questionnaires

Metacognition questionnaire

Pre- and post-metacognition questionnaires were hosted online through Qualtrics (Qualtrics, LLC., Drive Provo, UT). At the start of the course, students were invited to complete the pre-questionnaire, which included a demographics section (age, gender, program of study, and highest earned degree) and a modified metacognitive awareness inventory (MAI). The MAI, developed and extensively described by Schraw and Dennison (1994), is a 52-item questionnaire that assess metacognition across two overarching domains: knowledge of cognition (17 items) and regulation of cognition (35 items). The knowledge of cognition domain is further subdivided into declarative knowledge (8 items), procedural knowledge (4 items), and conditional knowledge (5 items) whereas the regulation of cognition domain is subdivided into planning (7 items), debugging strategies (5 items), comprehension monitoring (7 items), information management strategies (10 items), and evaluation (6 items; Table 2). 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 & Soemantri, 2018; Harrison & Vallin, 2018). The MAI was modified from its original 100-point slider or five-point Likert scale format to true-false answering to reduce student survey fatigue, a modification for which there are multiple precedents (Othman & Abdullah, 2018; Dunn et al., 2019; Tatić et al., 2019). Metacognitive awareness inventory 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

TABLE 1 Metacognitive discussion board prompts provided to students

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 have "learned" the material?
Examination 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?
Examination 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?
Examination 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?

TABLE 2 Summary of the metacognitive awareness inventory (MAI) categories

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

Abbreviation: MAI, metacognitive awareness inventory.

score. This modified version had an acceptable level of internal consistency, as determined by a Cronbach's alpha of 0.7 (Taber, 2018). 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 were shared with the students for their own benefit. Students were encouraged to contact an instructor with questions or concerns regarding their MAI results.

The post-questionnaire was administered one week prior to the end of the 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. 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.

Likert questions

During the synchronous laboratory sessions, students voluntarily responded to Likert questions using TopHat (TopHatMonocle Corp., Toronto, Ontario, Canada), an audience response system. Prior to each session, questions related to metacognitive practices were shared with students alongside formative practice questions pertaining to the recent material. The topics of the metacognitive questions included anticipated examination grades (1 = poor performance, 5 = strong performance), satisfaction with examination grades (1 = low satisfaction, 5 = high satisfaction), interest in block material (1 = not interested, 3 = interested), frequency of comprehension monitoring (1 = no, 2 = yes), and anatomy difficulty (1 = not difficult, 3 = difficult).

Qualitative data analysis

Discussion board responses were exported, collated, deidentified, and imported into Dedoose qualitative analysis software, version 4.12 (SocioCultural Research Consultants, LLC., Manhattan Beach, CA). Qualitative analysis was performed using Braun and Clarke's method of thematic analysis (Braun & 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 of the authors (A.S.C.) reviewed all discussion board responses to develop familiarity with items of interest related to the research questions. Following familiarization, one of the authors identified provisional codes inductively, allowing the data to drive the coding process from the bottom up. To evaluate initial coding reliability, a second author (M.A.M.) reviewed the initial coding, which was calculated with Cohen's Kappa (values ranging from 0.56 to 0.77, meaning moderate to substantial coding agreement) (McHugh, 2012). 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 was then applied to all discussion responses. After the coding process, codes were organized into provisional themes based on their relationships to one another. At last, the provisional themes were reviewed, defined, and named by two authors (A.S.C. and M.A.M.).

Statistical analysis

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

RESULTS

Participant demographics

A total of 109 (84%) and 59 (46%) 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 3. The demographics of the matched pairs were similar to and representative of the overall population of participating students.

Quantitative results

Metacognitive awareness inventory

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 ($p<0.001$). 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). 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 1). 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 ± 3.1, p = 0.01).

TopHat questions

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 rate how closely their anticipated examination grade matched their actual examination grade on a five-point Likert scale (1 = much lower, 3 = accurate, 5 = much higher), students rated their accuracy as 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). Students also indicated whether they had been monitoring their progress (yes = 78%, no = 17%) and rated the difficulty of learning anatomy at 1.9 ± 0.9 on a three-point scale (1 = easy, 3 = difficult).

Significant 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 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 correlated with actual examination grades for

TABLE 3 Summary of participant demographics

Characteristics	Doctor of physical therapy (DPT)	Master's of physician assistant studies (MPAS)	Doctor of occupational therapy (OTD)	Total
Participants; *n* (%)	41 (37.6)	35 (32.1)	33 (30.3)	109 (100)
Mean age; mean (±SD)	22.7(±2.6)	24.4 (±2.6)	22.7 (±2.5)	23.3 (±2.6)
Sex				
Female; *n* (%)	33 (35.9)	27 (29.3)	32 (34.8)	92
Male; *n* (%)	8 (47.0)	8 (47.0)	1 (5.9)	17
Highest earned degree				
Master's; *n* (%)	1 (25.0)	2 (50.0)	1 (25.0)	4
Bachelor's; *n* (%)	40 (38.1)	33 (31.4)	32 (30.5)	105

Abbreviations: DPT, doctor of physical therapy; MPAS, master's of physician assistant studies; OTD, doctor of occupational therapy.

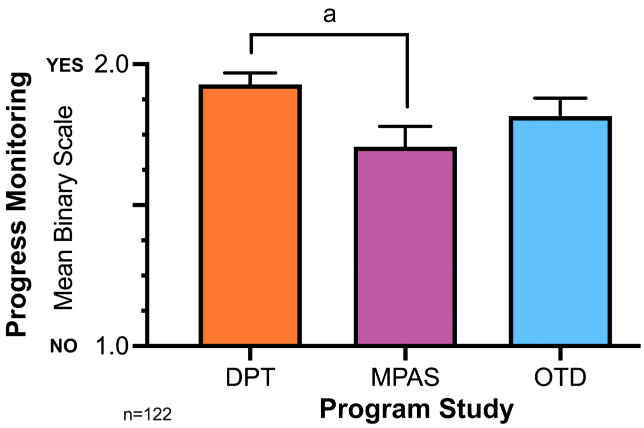

FIGURE 1 Progress of monitoring by program of study. Mean binary response (1 = no; 2 = yes) of students, separated by program, regarding whether they monitored their learning progress. Doctor of physical therapy students were found to monitor their progress significantly more than their MPAS colleagues ($p = 0.01$), 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. [a]$p < 0.01$.

all evaluated blocks; Blocks 1 ($r = 0.87$, $p < 0.001$), Block 2 ($r = 0.76$, $p < 0.001$), and Block 3 ($r = 0.67$, $p < 0.001$).

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 performed satisfactorily on assessments were able to anticipate such adequate grades, while those who scored lower were unable to anticipate such scores and were also dissatisfied (Figure 2A–F). In Block 1, both high and middle performers anticipated similarly strong examination performances that were significantly higher than low performers (High: 3.4 ± 0.9, Middle: 3.3 ± 0.9, Low: 2.5 ± 1.1; $p < 0.001$ and $p = 0.001$ respectively). Similarly, in Block 2, high and middle performers

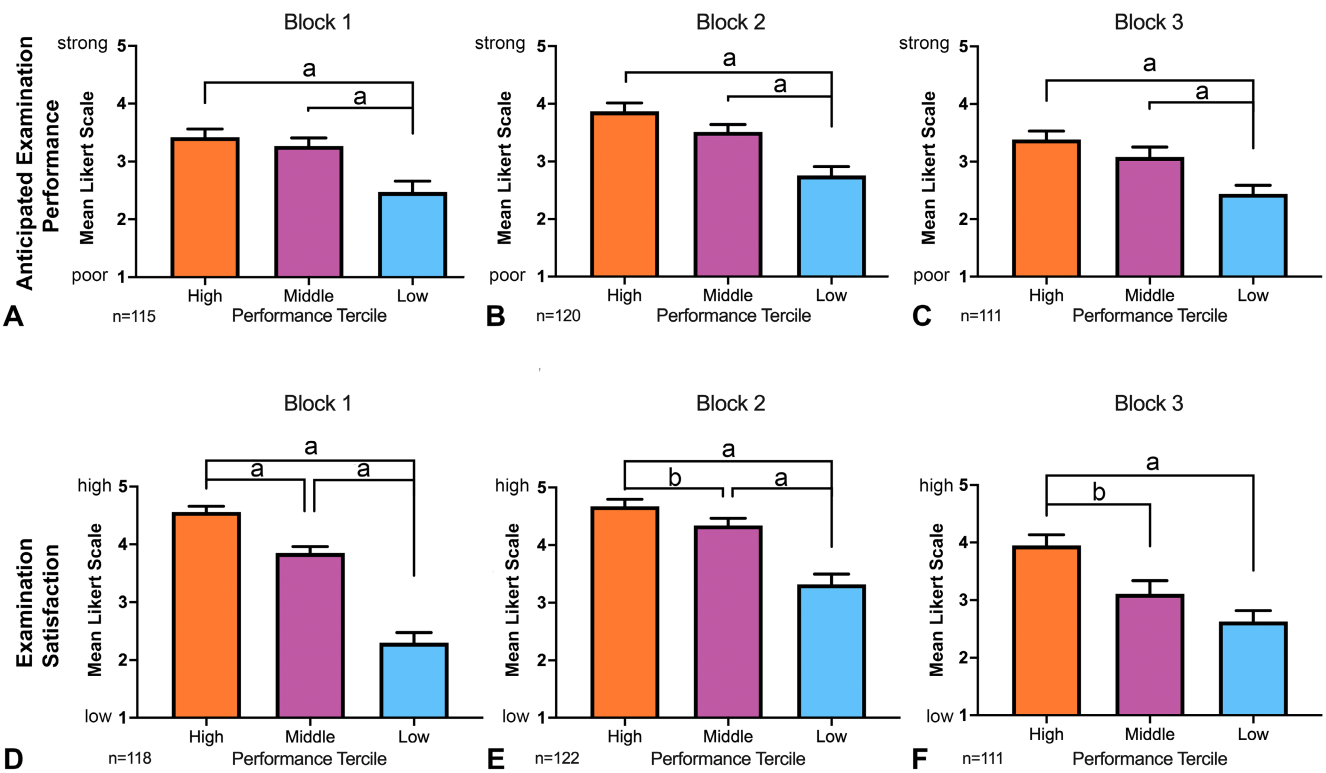

FIGURE 2 Block examination perceptions by performance tercile for each block evaluated. Anticipated examination performance and examination satisfaction was measured on a five-point Likert scale where 5 = strong performance/high satisfaction and 1 = poor performance/low satisfaction. High and middle performers anticipated similarly strong examination performances that were significantly higher than low performers in different blocks. Panel A, Block 1 (back and upper limb, $p < 0.001$ and $p = 0.001$ respectively); Panel B, Block 2 (thorax and abdomen, $p < 0.001$ and $p = 0.002$ respectively); and Panel C, Block 3 (pelvis and lower limb, $p < 0.001$ and $p = 0.004$ respectively). However, all three terciles varied significantly from each other in their examination satisfaction for different blocks. Panel D, Blocks 1 ($p < 0.001$); and Panel E, Block 2 ($p < 0.001$); On Block 3, (Panel F) high performers were significantly more satisfied than both middle ($p = 0.006$) and low ($p < 0.001$) performers, who were similarly satisfied. Performance tercile: High, top 33% of performers in overall course; middle, middle 33% of performers in overall course; and low, lowest 34% of performers in overall course. [a]$p < 0.001$; [b]$p < 0.05$.

predicted strong examination performances compared to their low performer peers (High: 3.9 ± 0.9, Middle: 3.5 ± 0.8, Low: 2.8 ± 1.0; $p < 0.001$ and $p = 0.002$, respectively). Finally, in Block 3, the high and middle performers once again anticipated stronger examinations than the low performers (High: 3.4 ± 0.9, Middle: 3.1 ± 1.1, Low: 2.4 ± 0.9; $p < 0.001$ and $p = 0.004$ respectively). However, all three terciles varied significantly from each other in their examination satisfaction (Figure 2D–F). For Block 1, high performers were the most satisfied followed by the middle performers and then the low performers (High: 4.6 ± 0.6, Middle: 3.9 ± 0.7, Low: 2.3 ± 1.1; $p < 0.001$). Similar differences in satisfaction were also identified in Block 2 (High: 4.7 ± 0.8, Middle: 4.3 ± 0.8, Low: 3.3 ± 1.2; $p < 0.001$). On Block 3, high performers (3.9 ± 1.2) were significantly more satisfied than both middle (3.1 ± 1.4; $p = 0.006$) and low (2.6 ± 1.1; $p < 0.001$) performers, who were similarly satisfied.

Qualitative results

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: *repetitive study strategies*, *quizzing*, *monitoring learning*, *time constraints*, *modifying study strategies, and test comprehension* (Table 4).

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

TABLE 4 Summary of themes identified from metacognitive discussion board responses

Themes	Description
Repetitive study strategies	Students relied heavily on study strategies that required them to repeat an activity multiple times to meet their learning needs. Some strategies involved rote repetition (e.g., reviewing flashcards, re-writing notes) while others were more purposeful (e.g., watching lectures once to preview and re-watching to take notes)
Quizzing	Students heavily relied on quizzing themselves (e.g., practice questions or flash cards) to self-assess their learning and monitor their progress
Monitoring learning	Students engaged in metacognitive monitoring of their learning early in the course, but found it difficult to maintain as the course progressed
Time constraints	Students believed that time constraints such as the pace of the course or competing responsibilities limited their ability to study and influenced their choice in study strategies
Modifying study strategies	Students were open to modifying their study strategies early in the course but became less receptive to changes as the course progressed
Test comprehension	Early in the course, the most common examination errors involved test comprehension (e.g., misreading questions, lack of specificity, and/or lack of confidence)

> 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.

DISCUSSION

This 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. 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 among 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; Versteeg et al., 2021).

While previous studies have shown that reflective writing can improve student metacognition (Stanton et al., 2015; Alt & Raichel, 2020; O'Loughlin & 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 (Kruger & Dunning, 1999; Ehrlinger et al., 2008; Sawdon & 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 the factual and foundational knowledge needed before higher order application. 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.

Based on the insights gained from this study, several recommendations can be offered for educators who seek to implement metacognitive activities into their courses, particularly for allied health students. 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. Although all students would likely benefit from metacognitive training, based on the present data middle performers may benefit the most, considering they were identified as the group with the greatest metacognitive disconnect. Outside of the present method using discussion boards and/or reflective writing, many types of activities have been indicated to improve metacognition among students, such reflective exam wrapper assignments (Schuler & Chung, 2019), team-based learning (Martirosov & Moser, 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).

Study limitations and future directions

As with any research study, this study is not without its limitations. Due to the Covid-19 pandemic and its associated restrictions, all elements of the 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, as outlined above, 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 & 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, which will allow for comparison of metacognition across student populations. Finally, 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.

CONCLUSIONS

Metacognition is a powerful skill that can greatly benefit the academic and clinical performance of allied health students, and in particular middle performing students. While educators may be eager to incorporate metacognitive activities such as reflective writing into their health professions courses, student receptiveness to these activities is not static across the span of a course. Concurrent academic and professional responsibilities external to the course accumulate over time, leading students to triage their responsibilities and become reluctant to practice their metacognitive skills, even if they already possess those skills. Careful consideration of the timing and placement of metacognitive activities can help maximize their effectiveness on student metacognition, particularly for certain populations of students.

ACKNOWLEDGMENTS

The authors thank the 2020 "Anatomy for Healthcare Professionals" cohort of Doctor of Physical Therapy (DPT), Master of Physician Assistant Studies (MPAS), and Doctor of Occupational Therapy (OTD) students for their participation in this study and Dr. Jessica Byram, Ph.D. for her guidance on qualitative analysis. The authors report no conflict of interests.

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How to cite this article: 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