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RESEARCH REPORT

Pre- and post-examination reflections of first-year medical students in an integrated medical anatomy course

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Abstract

Due to the rigor and pace of undergraduate medical anatomy courses, it is not uncommon for students to struggle and fail initially. However, repetition of coursework places an additional burden on the student, instructor, and institution. The purpose of this study was to compare the exam preparation strategies of repeating and non-repeating students to identify areas where struggling students can be supported prior to course failure. As part of their integrated anatomy course, first-year medical students at Indiana University completed a metacognitive Practice-Based Learning and Improvement (PBLI) assignment prior to and after their first exam. In the PBLIs, students were asked to reflect on their exam preparation strategies, confidence, and satisfaction, as well as their predicted and actual exam performance. PBLI responses from non-repeating and repeating students were then analyzed quantitatively and qualitatively. A total of 1802 medical students were included in this study, including 1751 non-repeating and 51 repeating students. Based on their PBLI responses, non-repeating students were appropriately confident, somewhat satisfied, and more accurate when predicting their exam performance. Repeating students were overconfident, dissatisfied, and inaccurate when predicting their first exam performance on their initial, unsuccessful attempt but were more successful on their second, repeat attempt. Qualitative analysis revealed that repeating students aimed to improve their studying by modifying their existing study strategies and managing their time more effectively. In conjunction with other known risk factors, these insights into repeater and non-repeater exam preparation practices can help anatomy educators better identify and support potential struggling students.

KEYWORDS
anatomy, exam preparedness, metacognition, remediation, study strategies

INTRODUCTION

The transition from pre-professional education to undergraduate medical education often requires newly matriculated students to reevaluate how they study. Unlike in pre-professional education, medical students are expected to self-direct their own learning by independently setting learning goals, managing study time, and identifying appropriate study strategies (Barbosa et al., 2016; Picton et al., 2022). As a result, some students may discover that their previously effective approaches to studying are no longer sufficient for the rigorous medical curriculum, putting them at risk of academic hardship or possibly even failure (Reaume & Ropp, 2005).

To adapt their study strategies, students may need to rely on their metacognition, the process of thinking about one's own thinking (Barbosa et al., 2016). More specifically, metacognition is defined as the ability to plan, monitor, and evaluate one's own learning and performance (Lai, 2011). 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 (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).

Engagement in metacognitive self-reflection at various points of the learning process helps students better identify gaps in their knowledge as well as the strengths and weaknesses of their study strategies (Stanton et al., 2019). For example, metacognitive reflection on incorrectly answered examination questions may help a student identify patterns of errors or deficiencies in their studying. Ultimately, this self-awareness leads to improved performance on examinations, projects, and homework assignments (Menekse et al., 2022). Specifically in undergraduate medical education, metacognitive skills have been linked with several improved educational outcomes, including more motivated, self-regulated learning (Hill et al., 2020; Siqueira et al., 2020), improved performance on standardized assessments (Chang et al., 2021), increased proficiency in surgical skills such as suturing and knot-tying (Gardner et al., 2016), enhanced clinical decision-making (Chew et al., 2016), and improved skill in writing medically appropriate prescriptions (Hennrikus et al., 2018). Conversely, a lack of metacognitive skills can lead to an overestimation of abilities or reduced self-monitoring and, thus, poor academic performance or even medical errors (Moulton et al., 2010; Medina et al., 2017; Royce et al., 2019).

Despite their best efforts, some medical students fail to adjust their study strategies and subsequently struggle academically. While medical students can struggle at any point during their education, it is most likely during their first year when they are still adapting to the demands of the rigorous medical school curriculum (Picton et al., 2022). Previous studies have estimated that 10%–15% of students will struggle during their undergraduate medical programs (Yates & James, 2007; Frellsen et al., 2008; O'Neill et al., 2016; Picton et al., 2022), though rates as high as 37%–47% have been reported (Sladek et al., 2016; Li et al., 2019). These rates may be even higher considering struggling students often fly under the radar of educators (Li et al., 2019). Due to their fear of failure and the competitive nature of medical school, struggling medical students may feel ashamed to admit they are struggling and in need of assistance (Picton et al., 2022). Students may struggle for a variety of reasons, but several are related to how they study and learn. Some struggling students are considered "at capacity" and are unable to adapt their study strategies to the volume and pace of self-directed learning required by medical education (Picton et al., 2022). Others are academically capable "slow starters" and require more time to adjust their study strategies to the medical school curriculum (Picton et al., 2022). Unfortunately, once they fall behind in their coursework, it is nearly impossible for them to catch up (Picton et al., 2022). Students can then go on to fail their coursework and require academic remediation.

Remediation in medical education is defined as "the act of facilitating a correction for trainees who started out on the journey toward becoming a physician but have moved off course" (Kalet & Chou, 2013). Between 7% and 28% of medical trainees will undergo remediation at some point during their education, which has a success rate ranging between 77% and 100% (Guerrasio et al., 2014; Chou et al., 2019). However, the evidence is unclear as to whether remediation processes effectively address the failing students' gaps in knowledge or skills (Pell et al., 2012; Cleland et al., 2013), and many remediation interventions are more focused on improving performance on a specific knowledge or skills examination rather than supporting lifelong, self-regulated learning skills (Cleland et al., 2013).

Remediation can have significant financial consequences for all stakeholders involved, including the struggling student, the faculty, and the institution (Guerrasio et al., 2014). In a cost analysis by Foo et al. (2017), remediation for a single medical student at a government-funded university in Australia costs nearly US$9400, 49% of which is borne by the student. The financial burden is likely even greater for students in the United States (Foo et al., 2017). Medical educators and the institution itself also bear some of the financial burden of remediation through increased instruction time and educational resources (Foo et al., 2017; Mills et al., 2021). There are several intangible consequences of remediation as well. Remediation is often stigmatized, leading students who need to remediate to experience negative emotions such as shame, fear, and frustration, which can further hinder their ability to effectively remediate (Mills et al., 2021). Repeating a year of coursework can also isolate students, leading to the loss of their social support network (Picton et al., 2022). Additional faculty time toward remediation means a loss of time that could have otherwise been dedicated toward research, clinical care, or professional development (Foo et al., 2017). Furthermore, educators who oversee struggling students often experience an emotional burden, such as feeling guilty for letting down their students or inadequacy in their skills as educators (Foo et al., 2017).

One of the most effective methods for remediating students is by being proactive and identifying struggling students early (Cleland et al., 2013; Chou et al., 2019; Picton et al., 2022). Early identification allows educators to intervene and provide struggling students with the academic support they need to recover prior to examination or course failure, thereby avoiding much of the economic and emotional costs of remediation (Picton et al., 2022). Many previous studies have sought to identify possible predictors for how medical students will perform academically in medical school. These factors include premedical background (Hortsch & Mangrulkar, 2015; Fagalde & McNulty, 2023), study strategies (McNulty et al., 2012; West et al., 2014), self-regulated learning skills (Barbosa et al., 2016), performance on examinations, unprofessional behavior, and health problems (Chou et al., 2019). However, the evidence is still somewhat unclear as to how these factors can be used to reliably predict future academic performance.

In short, student metacognition improves academic performance and can assist in preventing remediation, which is a huge burden on students and faculty and is not always successful. However, methods to improve student performance must be implemented early on in their curricula. Therefore, this study was designed to explore how undergraduate medical students prepare for examinations in an integrated gross anatomy course and determine if there are any significant differences between how repeating and non-repeating students reflect on and apply those preferred exam preparation strategies. The study is built on the theoretical framework that engaging in self-directed learning activities demonstrates the metacognitive processes that students use to assess their exam preparedness and can help identify students who lack the metacognitive skills to appropriately adapt their study strategies in response to a poor exam performance. The research questions to be addressed in this study include: (1) how accurate are repeating and non-repeating students at predicting their performance on their first integrated anatomy exam, (2) what relationships are present between the examination confidence, satisfaction, predicted scores, and actual scores of repeating and non-repeating students, (3) what do undergraduate medical students focus on when they reflect on their exam preparation strategies before and after their first integrated anatomy exam, (4) how do the self-described exam preparation strategies of undergraduate medical students 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?

A multiple-methods approach was used to address the aforementioned research questions. The authors hypothesized that non-repeating students would be able to predict their performance on the first anatomy exam with greater accuracy than their repeating counterparts. The authors also hypothesized that non-repeating students would exhibit a positive relationship between their confidence, satisfaction, predicted scores, and actual scores, whereas their repeating peers would not. Questions three through five were addressed using an inductive approach to qualitative methods, and as such, there were no a priori hypotheses. Rather, the aim of these qualitative elements was to provide insights into what undergraduate medical students perceived as effective exam preparation strategies and how these perceptions changed after their first examination.

MATERIALS AND METHODS

Study overview

This study was given exempt status by the Indiana University Institutional Review Board (Protocol #1509117450). Five cohorts of first-year undergraduate medical students at all nine campuses of the 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 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 examinations (see below for criteria for course failure).

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 and 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) the 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.

Course description: Human structure

Course overview

"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 have remained consistent.

Summative assessments include four block examinations in 2016–2019, which were reduced to three in 2020 to accommodate a change in scheduling, and one final cumulative examination. Each of the block examinations consists 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% for the customized NBME final. Although the grading structure changed, there were no notable changes in the number of students who passed or failed the course.

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) prior to and following the first Human Structure exam (Hoffman & 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. Each student then submitted their pre-exam PBLI to their campus' Human Structure site director for review and received brief feedback on their exam preparation strategies. Depending on the size of the student cohort at each campus, each site director may have about 20–150 pre-exam PBLIs to review prior to the first exam. As a result, the method and specificity of feedback for students often varied between campuses. Two weeks after the first exam scores are released, students must complete the post-exam PBLI, which consists of open-ended ($n=2$) and closed-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. Students then submitted the post-exam PBLI to their Human Structure site director for review and brief feedback.

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.

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 1. Descriptive statistics were then calculated, and the 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% and 91%, "Low Pass" students scored between 70% and 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 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. 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. The 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

TABLE 1 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%)	

Abbreviation: PBLI, practice-based learning and improvement.

against that of the repeating students using the Kruskal–Wallis H test. Results for all statistical analyses were considered significant if $p < 0.05$.

Qualitative analysis

For the repeating students, open-ended PBLI responses from their initial, unsuccessful attempt were qualitatively analyzed 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 a 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 authors individually familiarized themselves with the same subset of responses from the repeating students ($n = 8$) (Step 2). Afterwards, each author independently coded that same subset using an inductive approach (Step 3). The authors then reconvened to discuss code applications and create an analytical framework and a single, unified codebook. Each author then used the unified codebook to code differing sets of responses ($n = 8$). Any new codes were discussed and added to the unified codebook (Step 4). A single author (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.

RESULTS

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 their first year in its entirety. A more detailed breakdown of participant demographics can be found in Table 2.

TABLE 2 Summary of participants.

	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

Repeating undergraduate medical students

Quantitative

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 comparison to the repeating students' initial and repeat attempts, the actual exam score, confidence, and satisfaction ($p < 0.001$) all exhibited statistically significant improvements, whereas the predicted score remained consistent (Figure 1).

Qualitative

Several overarching themes were identified through framework analysis of the pre- and post-exam PBLIs from the repeating students' initial, unsuccessful attempt, including: Enhance Existing Study Strategies, Time is Precious, Back to the Anatomy Lab, and Practice Questions: A Double-Edged Sword (Supporting Information Appendix S1).

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.

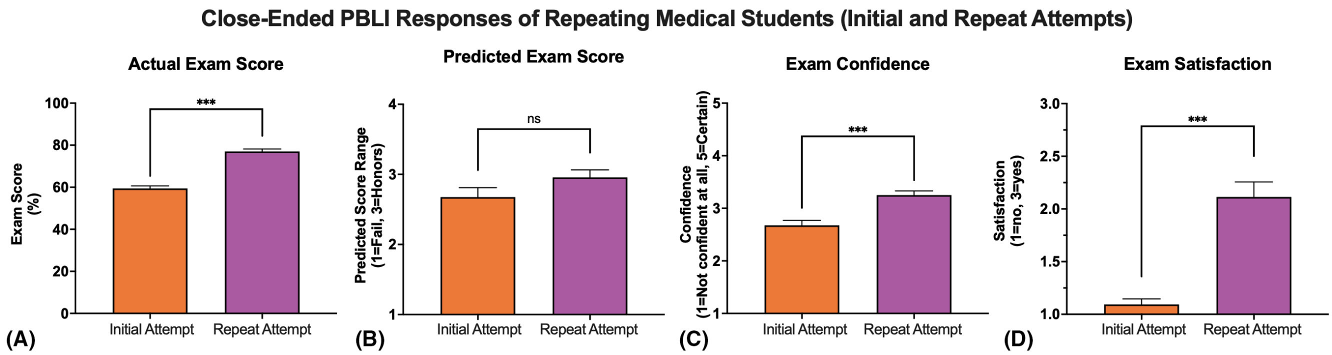

FIGURE 1 Close-ended practice-based learning and improvement responses of repeating medical students (initial and repeat attempts). Repeating students were overconfident, dissatisfied, and inaccurate when predicting their exam performance on their first attempt but were more successful on their second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

> 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 to 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 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 as a useful supplement to their exam preparations, particularly for self-assessment of their knowledge:

> 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 were not 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.

Non-repeating undergraduate medical students

Quantitative

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) (Figure 2). Non-repeaters also exhibited statistically significant correlations between actual examination score, predicted score, confidence, and satisfaction ($p<0.001$). Linear regression determined that the predicted score was a statistically significant ($p<0.001$) predictor of the actual score and accounted for a small amount of variance ($r=0.178$, adjusted $R^2=0.03$).

When non-repeaters were organized based on performance tiers, each tier was found to be largely inaccurate in predicting their first examination scores. Linear regression determined that the predicted score was no longer a statistically significant predictor of the 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 3).

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).

Qualitative

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" (Supporting information Appendix S1).

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

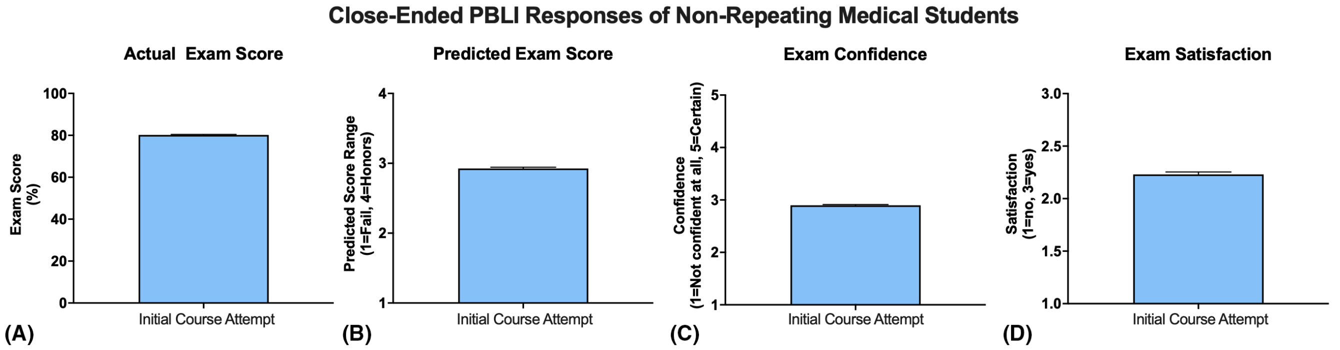

FIGURE 2 Close-ended practice-based learning and improvement responses of non-repeating students. Non-repeating students were appropriately confident, somewhat satisfied, and more accurate when predicting their exam performance. (A) Actual Exam Score: 0%–100%. (B) Predicted Exam Score: 4 = >92% ("Honors"); 3=85%–91% ("High Pass"); 2=70%–84% ("Pass"); 1=<70% ("Fail"). (C) Confidence: 5=Certain; 4=High Confidence; 3=Moderate Confidence; 2=Low Confidence; 1=Not at all confident. (D) Satisfaction: 3=Yes; 2=Not Sure; 1=No. *$p<0.05$; **$p<0.01$; ***$p<0.001$.

TABLE 3 Performance tier distribution of non-repeating students.

		Performance tier				
		Honors (>92%)	High pass (85%–91%)	Pass (70%–84%)	Fail[a] (<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

[a]Students in the “Fail” category failed their first exam, but ultimately went on to pass the course.

> 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.

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.

DISCUSSION

This 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 (Cale et al., 2023). 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 & Dunning, 1999; Sawdon & Finn, 2014). This cognitive bias causes individuals with limited knowledge to significantly overestimate their performance due to an inability to recognize their own deficiencies, leading them to inaccurately predict their performance (Kruger & 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. Although this cognitive phenomenon has been previously documented in the medical education literature (Steuber et al., 2017; Gabbard & Romanelli, 2021), this study further expands upon it by focusing on the context of anatomy education specifically, by spanning multiple years, including across the COVID pandemic, and by outlining the thought processes of these students through qualitative data.

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 & Erinjeri, 2008; Roediger & Butler, 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. The 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 as their primary method of building their foundation of knowledge and learning the material in the first place, rather than for self-assessment. While this approach can help students identify and address gaps in 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. Based on these findings, over-reliance on practice questions as a primary method of studying may be a warning that a student may be at risk of struggling in the future.

Qualitative analysis of the repeating and top-performing students' PBLI reflections also indicates 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 than 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 than switching to something different. This "doubling down" on a familiar study strategy rather than exploring other potential strategies has been previously documented in allied health students (Cale et al., 2023). 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 et al. (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 & 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 & Sadoski, 2011). Additionally, time management provides non-academic benefits by supporting mental well-being and reducing burnout (Barbosa et al., 2016).

Based on the insights gained from this study, several recommendations can be offered to aid in identifying and supporting struggling students prior to the need for remediation. In addition to known risk factors such as Under-Represented in Medicine (URiM) status (Brosnan et al., 2016; Joseph et al., 2021) or lack of prior laboratory-based anatomy experience (McNulty et al., 2016; Robertson et al., 2020), educators may also want to consider how a student applies their metacognition and uses their study resources when identifying and supporting potential struggling students. To support the ability to metacognitively monitor exam preparedness, educators should provide students with ample information regarding examination format and expectations, as well as practice quizzes or questions in a format similar to the actual examination. 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.

Study limitations and future directions

This study is not without its limitations. 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 help mitigate any influence online learning may have had on the data, and indeed allows evaluation of metacognitive practices across multiple learning climates, from pre-COVID in-person learning through to post-COVID hybrid or blended learning, which provides a more comprehensive look at how students approached their studying within a medical curriculum. Additionally, no themes emerged from the data that were related to online learning, indicating that such instruction did not influence students' perceptions of exam preparation.

The effectiveness of the PBLI assignments was also limited by the ability of the Human Structure course directors at each campus to provide specific, actionable feedback for each student's exam preparation strategies. The enrollment in Human Structure varies greatly across the IUSM branch campuses, ranging from 20 to 150 medical students. As a result, it was not always feasible for each course director to provide detailed feedback for each student in a timely manner, particularly at campuses with higher enrollment. Since feedback is a critical component of self-directed learning as defined by the LCME and in the development of metacognitive skills, this discrepancy in feedback quality may have impacted if or how students prepared for subsequent exams (Lai, 2011; LCME, 2022). In the future, this limitation can be addressed by implementing a comment-building tool that can be used to generate high-quality, customized feedback that is tailored to each student and provides actionable recommendations for improvement (Hoffman et al., 2023).

Another key limitation of this study involves the timepoints at which the PBLIs were administered to the students. Since its inception, the PBLI has only ever been administered before and after the first Human Structure examination. This introduces the students to the practice of metacognitive reflection early in their education but limits our ability to determine if or how metacognitive ability and exam preparation strategies change over subsequent exams. Future iterations of the PBLI could be deployed after subsequent Human Structure exams to encourage students to continue the practice of metacognitive reflection as well as facilitate longitudinal data collection on student metacognition and exam preparation strategies. However, work completed by the authors has found that students are most receptive to changes in their learning strategies early on within a professional medical course, with little change occurring following subsequent exams, which supports the placement of the PBLI activity within this curriculum (Cale et al., 2023). More broadly, several other factors may have also contributed to a student's likelihood of struggling in Human Structure and medical school as a whole, such as an URiM background or a lack of laboratory-based anatomy experience. These factors were not explicitly explored in this study but may have predisposed an individual student to struggling. Therefore, a student's metacognitive abilities and study strategies should be considered in conjunction with these other factors when identifying students who are likely to struggle with anatomy and medical school.

This study could also be further expanded longitudinally by implementing the PBLI in subsequent courses and exploring how the examination preparation strategies and metacognitive abilities of undergraduate medical students change across the other basic science courses of the medical curriculum. An additional longitudinal study could also compare the examination preparation strategies and metacognitive reflections of medical students across the pre-, mid-, and post-COVID years to determine if there are any significant differences.

Future studies should focus on promoting the metacognitive abilities of students as well as addressing known risk factors for course failure, such as poor time management or the inflexibility of study strategies. Educators can support the students' metacognitive abilities by providing them with additional information about the assessments as well as authentic opportunities for students to self-assess themselves, such as practice quizzes. These additions can help medical students metacognitively monitor and evaluate their examination preparedness with greater accuracy.

CONCLUSIONS

The transition into undergraduate medical education can be jarring and challenging for first-year medical students. When presented with this challenge, top-performing students are adept at using their metacognitive abilities to self-assess their knowledge, identify deficiencies, and adjust their study strategies to the new curriculum. Conversely, low-performing students lack such skills and are less successful with self-regulated learning, sometimes failing the course and requiring remediation. With these insights in mind, educators should aim to identify and support struggling students who are at risk of course failure by developing their metacognitive abilities and study strategies, thereby hopefully preventing the need for costly remediation.

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CONFLICT OF INTEREST STATEMENT

The authors report no conflict of interests.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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