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RESEARCH REPORT

Histology education in an integrated, time-restricted medical curriculum: Academic outcomes and students' study adaptations

William Gribbin[1] | Eric A. Wilson[1] | Suzy McTaggart[2] | Michael Hortsch[3,4]

[1]University of Michigan Medical School, Ann Arbor, Michigan, USA

[2]Office of Medical Student Education, University of Michigan Medical School, Ann Arbor, Michigan, USA

[3]Department of Learning Health Sciences, University of Michigan Medical School, Ann Arbor, Michigan, USA

[4]Department of Cell and Developmental Biology, University of Michigan Medical School, Ann Arbor, Michigan, USA

Correspondence
Dr. Michael Hortsch, Department of Cell and Developmental Biology, University of Michigan Medical School, 109 Zina Pitcher Place, Ann Arbor, MI 48109, USA.
Email: hortsch@umich.edu

Abstract

In an ever-changing medical curricular environment, time dedicated for anatomical education has been progressively reduced. This happened at the University of Michigan Medical School starting in 2016–2017 when preclinical medical education was condensed to one year. Histology instruction remained integrated in organ system courses but reduced to a lecture-only format without scheduling time for laboratory exercises, requiring students to study virtual histology slides on their own time. In accordance with the shortened instructional time, the number of histology examination questions was reduced more than twofold. This study analyzed students' histology examination results and assessed their motivation to learn histology and use of educational opportunities before and after these curricular changes were implemented. Students' motivation to learn histology and their evaluation of histology lectures increased in the new curriculum. However, students devoted less study time to studying histology. Students' cumulative histology examination scores were significantly lower in the new curriculum and the number of students with overall scores <75%, defined as a substandard performance, increased more than 15-fold. Academically weaker students' histology scores were disproportionately more affected. As medical educational strategies, priorities, and curricular frameworks continue to evolve, traditional didactic topics like histology will need to adapt to continue providing educational value to future health care providers.

KEYWORDS
histology education, medical curriculum, medical education, students' performance, undergraduate medical education

INTRODUCTION

For more than a century, histology/microanatomy has been an integral part of preclinical medical education (Bennett, 1956; Hightower et al., 1999; Hussein et al., 2015; McBride and Drake, 2018). Based on the cell theory of life that was first formulated by Theodor Schwann in the first half of the 19th century (Schwann, 1838), histology encompasses a structural description of cells, tissues, and organs and links these structural attributes to their biological function. This is especially important for aspiring health care providers as many human disorders are cellular in nature. A detailed understanding of cellular differentiation, structure, and function is a key foundational element of the biomedical basic sciences and for disease diagnosis and treatment.

Traditionally, histology or microanatomy has been taught in two distinct steps or components: (1) a didactic transfer of basic knowledge, either in a lecture or a self-learning format and (2) a skill-building laboratory component that helps students acquire the ability to scientifically

The first two authors contributed equally to all aspects of the project.

analyze visual material, specifically microscope images (Drake et al., 2002). In the past, this second step was based on laboratory work involving light microscopes and prepared tissue specimens (Huber, 1900; Bracegirdle, 1977). More recently, technological advances, like virtual microscopy and the Internet, have dramatically changed histology education (Heidger et al., 2002; Michaels et al., 2005; Bloodgood & Ogilvie, 2006; Mione et al., 2013). However, these changes had relatively little influence on the dichotomy of histology teaching having a didactic and a laboratory component and their respective educational goals and contributions. Both components have been successfully taught online, reducing the need for extensive direct teacher–learner interactions (Barbeau et al., 2013; Mione, et al., 2013; Thompson & Lowrie, 2017; Lee et al., 2020). However, in some circumstances, in-person, instructor-guided histology laboratory sessions have been correlated with superior learning outcomes compared with online-only learning (Selvig et al., 2015; Zureick et al., 2018). These technological innovations have transformed histology teaching worldwide and are being introduced (in varied orders and at different speeds depending on locality) to replace the old lecture and light microscope format, often in combination with curricular reforms (Sherer et al., 2014; Lu et al., 2016; Yohannan et al 2019; Cheng et al 2020; dos Santos et al., 2021).

Over the last several decades, the time allocated to anatomical education in preclinical medical curricula has significantly decreased (Drake et al., 2002, 2014; McBride & Drake, 2018). More recently, medical curriculum reforms have further reduced the time medical students spend on studying basic science subjects to permit earlier entry into clinical rotations (O'Connor Grochowski et al., 2007; Scudder et al., 2019; Daniel et al., 2020). Consequently, time-intensive instructional events like histology laboratory sessions were either reduced, substituted with online exercises, or altogether removed from the curriculum. Starting with the 2016–2017 academic year, the University of Michigan Medical School (UMMS) introduced a condensed, one-year preclinical curriculum (Daniel et al., 2020). Although histology remained integrated into organ-based courses or sequences, the new curriculum no longer included scheduled, faculty-guided laboratory sessions, leaving the acquisition of image analysis skills to students' independent study time.

The starting hypothesis of the work presented in this article assumed that significant reductions in teaching time for histology might result in changes of students' histology knowledge and skills. The data presented also report on how students adapted their histology learning strategies and their use of educational resources to the new curricular framework.

MATERIALS AND METHODS

Study population: UMMS student body

Each year, approximately 170 students matriculate to the UMMS medical program (Table 1). The sampling frame of this study consisted of 1009 first-year (M1) UMMS students from the academic years 2010–2016 studying histology under the old medical curriculum and of 511 UMMS first-year medical (M1) students from the academic years 2016–2019 studying histology in the new curricular system. Three M1 cohorts with a total of 503 students from the old curriculum (academic years 2013–2016) and one M1 class with a total of 166 students from the new curriculum (academic year 2018–2019) were surveyed in more detail about their attitudes toward learning histology, as well as time devoted to histology study and corresponding resource usage. Only students who completed the histology component in their respective curriculum were included in these counts and in the following analysis.

Histology lectures and laboratory hours in the old curriculum

The old, 17 months of integrated preclinical curriculum at UMMS (prior to the academic year 2016–2017) featured histology in eight organ-system-based sequences (courses) from September through March of the M1 year. Histology was not taught in the M2 year. Each sequence contained one to five traditional histology lectures that were followed by faculty-guided laboratory sessions, typically taking place on the same afternoon as the lectures. In total, the old M1 histology component offered 23 to 27 hours of lectures and 21 or 22 three-hour long laboratory sessions (Table 2). Neither lecture nor laboratory attendance were mandatory or documented.

Laboratory sessions began with a 30-minute, lecture-style introduction describing the relevant virtual slide material, followed by independent or group-based completion of laboratory assignments as laid out by the Michigan Histology website (UMMS, 2021). Histology faculty were available for the full three-hour duration of laboratory sessions to answer students' questions and to guide them through the assignments. The Michigan Histology website with virtual slides can also be accessed remotely by students for independent study without faculty guidance (UMMS, 2021). Students attending laboratory sessions also had access to light microscopes with glass slides and poster-size labeled electron micrographs that are featured on the Michigan Histology website. Lecture slides, laboratory introduction slides, and a collection of electronic review materials created by UMMS histology faculty were available for download from a password-protected server (Holaday et al., 2013). Students were encouraged, but not required, to supplement lecture and laboratory material with a histology textbook.

As a trial, two sequences, Gastrointestinal and Musculoskeletal (GI and MSK), in the academic year 2015–2016 followed the new curricular format without eliminating faculty-guided histology laboratory sessions. Time for laboratory histology instruction was shortened from three to two hours for several sequences, and the laboratory sessions in the GI sequence were combined with pathology instruction that was provided by faculty members of the Department of Pathology. The MSK sequence had traditional histology-only laboratory sessions. The Dermatology/Skin sequence that year had no scheduled histology instruction.

TABLE 1 Characteristics and examination performance of first-year medical (M1) students at the University of Michigan Medical School in old and new medical curriculum

	Old medical curriculum						New medical curriculum			Statistical analysis (old vs. new) *P*-value (Cohen's *d*)
Academic year	**2010–2011**	**2011–2012**	**2012–2013**	**2013–2014**	**2014–2015**	**2015–2016**	**2016–2017**	**2017–2018**	**2018–2019**	
Number of students, who completed the M1 year	168	167	171	167	170	166	164	181	166	
College GPA average of M1 class (±SD)	3.77 (±0.2)	3.78 (±0.18)	3.78 (±0.18)	3.77 (±0.19)	3.79 (±0.19)	3.78 (±0.19)	3.79 (±0.18)	3.77 (±0.2)	3.78 (±0.18)	0.81 (0.23)
College science GPA average of M1 class (±SD)	3.72 (±0.26)	3.75 (±0.22)	3.75 (±0.22)	3.73 (±0.24)	3.77 (±0.24)	3.75 (±0.25)	3.75 (±0.23)	3.71 (±0.27)	3.72 (±0.25)	0.21 (0.93)
First-year medical (M1) class examination performance for all subjects and for histology										
Total number of quiz and examination questions during the M1 year					1942	1559	1911	1925	1942	0.53 (0.91)
Cumulative class average % (±SD)					89.46 (±4.19)	90.25 (±4.18)	89.68 (±3.85)	89.92 (±3.78)	90.34 (±4.1)	0.81 (0.26)
Total number of histology questions	182	182	181	183	178	141	73	54	75	0.0017[a] (7.52)
% of histology questions of total M1 examination questions					9.2%	9.0%	3.8%	2.8%	3.9%	
Class average for histology questions % (±SD)	88.99 (±5.93)	88.71 (±5.7)	87.56 (±5.93)	88.01 (±5.5)	86.59 (±5.5)	86.52 (±5.86)	79.61 (±7.37)	82.03 (±8.13)	81.82 (±8.67)	0.004[a] (5.48)
Histology scores provided to students	Yes	Yes	Yes	Yes	Yes	Yes	Conditionally	No	No	
Number of students with a cumulative histology score of <75% (considered an unsatisfactory score)	4	3	2	2	1	2	39	37	33	0.0017[a] (14.91)
% of students with a cumulative histology score of <75%	2.4	1.8	1.2	1.2	0.6	1.2	23.8	20.4	19.9	

Note: The following data are presented: Number of UMMS M1 students completing the M1 year and their premedical overall and science GPA for the academic years 2010–2019, number of total examination questions and histology questions for the entire M1 year and total and histology cumulative class averages in the old and new curriculum, number and percent of UMMS M1 students with a year-end cumulative histology score below 75%. *P*-values were calculated using Welch's *t*-test. Effect sizes were determined using Cohen's *d* analysis. Abbreviation: GPA, grade point average. M1 class, first-year medical class;

[a]Significant *P*-values.

TABLE 2 Number of hours and quality evaluations of histology lectures and laboratory sessions scheduled in the University of Michigan Medical School in the old versus the new first-year (M1) medical curriculum

	Old medical curriculum						New medical curriculum			Statistical analysis
Academic year	**2010–2011**	**2011–2012**	**2012–2013**	**2013–2014**	**2014–2015**	**2015–2016**	**2016–2017**	**2017–2018**	**2018–2019**	***P*-value (Cohen's *d*)**
Histology lecture hours	27	25.5	25.5	23.5	23	23.25	27.25	24.75	27.75	0.13 (1.21)
Histology laboratory hours	66	63	63	66	63	39	6	0	0	
Topics without a histology component						Skin	Eye, ear, skin	Eye, ear, skin, endocrine	Eye, ear, skin	
Histology lecture quality										
Histology Lecture evaluations (1 = low to 5 = high) Means (±SD)	3.87 (±0.56)	3.92 (±0.4)	3.61 (±1.09)	3.91 (±0.74)	4.35 (±0.46)	4.01 (±0.52)	4.97 (±0.05)[a]	4.4 (±0.72)	4.42 (±0.45)	0.005[b] (2.74)
Number of lecture evaluations	17	17	17	17	16	16	2[a]	9	14	
Number of lecturers receiving at least one evaluation	11	12	11	9	10	11	1[a]	2	2	
Number of different lecturers	11	12	11	9	10	11	6[a]	2	2	

Note: The following data are presented: Hours of histology lectures and laboratory sessions scheduled in the University of Michigan Medical School old versus the new first-year (M1) medical curriculum; number of histology lectures and students' histology lecture evaluations in the old and new UMMS curriculum. *P*-values were calculated using Welch's *t*-test. Effect sizes were determined using Cohen's *d* analysis; [a]Only lecturers with a minimum of three lecture hours per sequence were evaluated. Therefore, the 2016–2017 academic year was excluded from the statistical analysis; [b]Significant *P*-value.

Histology lectures in the new curriculum

Starting with the academic year 2016–2017, all sequences followed the new curricular model. The M1 year started in July/August and usually lasted until the month of June of the following year. All histology instructions were reduced to lecture-only format with some lectures including the 30-minute, lecture-style presentations that were previously part of the laboratory session. During the 2016–2017 academic year, combined histology and pathology laboratory sessions were offered in the GI sequences. No histology laboratory sessions were scheduled starting with the academic year 2017–2018. Instead, students were encouraged to use the Michigan Histology website (UMMS, 2021) during their self-directed learning time. However, this was not presented to students as a required or expected assignment.

Sequence directors were given the freedom to allocate lecture time for histology, resulting in some topics/sequences no longer offering any histology instruction, specifically dermatology and ENT/ophthalmology (Table 2). Only quiz or examination questions from sequences with at least one official histology lecture were considered when calculating the cumulative histology student performance.

Histology lecturer evaluations

At the end of each sequence, a representative sample of the M1 class was invited to evaluate the lecturers from that sequence. Students were able to rate various aspects of each lecturer's presentation on a numerical five-point Likert scale and to add written comments. The average of all overall histology lecturer evaluations was calculated for each academic year (Table 2). Academic year 2016–2017 was excluded from the analysis of lecturer evaluation as only lecturers giving a minimum of three lectures in a single sequence were evaluated and only one histology lecturer was evaluated during that year (Table 2).

Assessment of student knowledge

During the preclinical phase of the four-year MD program at UMMS, students were/are graded on a satisfactory/unsatisfactory scale (Hortsch and Mangrulkar, 2015). M1 students at UMMS had weekly online quizzes and an end-of-sequence final examination. Questions from different subjects were proportional to the number of official instructional hours scheduled. Histology multiple-choice questions (MCQs) covering lecture and laboratory session material—usually with virtual microscopy or reference images—were interwoven into these assessments. In total, an average of 175 histology questions were administered during the M1 academic year in the old curriculum and an average of 67 histology questions in the new curriculum (Table 1). These MCQs were designed and submitted by the histology discipline director, usually reusing the same questions from year to year and maintaining an even mix of lower and higher Bloom's Taxonomy level questions (Zaidi et al., 2017). Cumulative histology scores (i.e., percent correct out of all histology questions) were the primary outcome measure for the M1 histology component and were used for assessing histology performance in this article.

Satisfactory performance was defined as earning an overall score of at least 75% in longitudinal disciplines like histology throughout the M1 year (Hortsch & Mangrulkar, 2015). No punitive action was taken if students in the old curriculum and in the 2016–2017 M1 cohort failed to maintain this 75% minimum cumulative average for histology. However, the Academic Review Board encouraged them to contact the histology discipline director (M.H.) to schedule individual mentoring sessions (Hortsch & Mangrulkar, 2015). Students in the new curriculum were required to maintain a 75% of higher cumulative average for individual organ sequences (to which histology examination questions contributed), but not for specific subjects.

Survey and data collection

At the conclusion of the M1 histology component, a link to an online survey was provided by email to UMMS classes in the academic years 2012–2013 to 2015–2016 and academic year 2018–2019 (Supplemental Material 1). The survey items were initially drafted by the histology course director (M.H.) followed by a careful review and editing process. The survey items used have been part of previous, now published research projects (Selvig et al., 2015; Zureick et al., 2018). Participation was voluntary and incentivized by three $70 USD cash prizes (or four cash prizes if the class response rate exceeded 90%) awarded each year by random drawing from the survey participants. The survey was constructed using the Qualtrics online survey software (Qualtrics, Provo, UT).

Four distinct subsections of the survey were grouped based on topic. The first group of survey questions asked students about their educational background, inquiring if they had worked in a basic science laboratory, had any prior experience in histology and/or pathology, were color vision–deficient, or were enrolled in the UMMS MD/PhD dual-degree program. The second group of survey questions used a five-point Likert scale to assess preferences for live lectures versus video podcasting and learning or study strategies used. The third group of survey questions quantified the amount of time students reported studying per lecture hour, group versus individual study behaviors, and perception of histology difficulty. The final group of survey questions asked students to reflect on their prioritization of histology in relation to other subjects taught simultaneously in the M1 curriculum, satisfaction with their final histology score, and perceived relevance of histology to their future career. Only results for the survey items relevant to the analysis described in this article are included. The 2019 survey was an abbreviated and slightly modified version of the previously published surveys (Selvig et al., 2015; Zureick et al., 2018) and is available as Supplemental Material File 1. For this survey all questions referring to histology

laboratory sessions were eliminated as this resource was no longer offered to students in the new curriculum. Response rates varied by year and ranged from 79.4% to 95.3%. Prior to data analysis, the histology discipline director (M.H.) deidentified all responses. This study received a nonregulated status from the University of Michigan IRBMED (HUM00162947).

Statistical analysis

Descriptive statistics including percentages, means, and standard deviations were calculated to summarize collected data and survey items. Survey responses were compared using chi-squared analysis or, in the case of binary-choice questions, Fisher's exact test using JASP, an open-source statistical program, version 0.11.1 (JASP, Amsterdam, The Netherlands). Baseline academic characteristics of students, the distribution of histology contact hours and lecture quality were compared using Welch's *t*-tests. The difference in average student academic histology performance across curricular versions for each quartile was analyzed by two-way ANOVA analysis. Where applicable, the results were further investigated using Tukey's HSD post hoc tests, and effect size was determined using Cohen's *d* analysis. The threshold for statistical significance was set at 0.05 and adjusted with Bonferroni correction in the case of multiple comparisons. These calculations were performed using Prism, version 8.4.2 (GraphPad Software Inc., La Jolla, CA).

RESULTS

Description of the UMMS M1 classes and survey participants

In the years 2010–2019, 167–181 UMMS medical students completed the histology component of their M1 year (Table 1). Classes entering the UMMS program had an average college grade point average (GPA) of 3.78 ±SD = 0.01 for the old curriculum and 3.78 ±SD = 0.01 for the new curriculum. Similarly, the average college science GPA numbers for classes entering the old (M = 3.75, ±SD = 0.02) versus the new (M = 3.73, ±SD = 0.02) did not vary significantly by cohort (Table 1).

Overall, 439 of 507 (86.6%) UMMS M1 students participated in the survey distributed to three M1 classes from 2014 to 2016 (Zureick et al., 2018). For several questions analyzing histology lecture attendance and lecture video usage, this data set was pooled with responses from earlier surveys dating from the academic years 2011 to 2013 (Selvig et al., 2015), yielding 888 participants (87.7%). A few students did not answer all questions, resulting in different counts for some questions. As a representative sample for students experiencing the new UMMS preclinical curriculum, the M1 class of 2018–2019 was surveyed. Of 166 students completing the M1 histology component in 2019, 113 students (68.1%) responded to the survey.

Differences between histology instruction in the old versus the new UMMS curriculum

In the old UMMS medical curriculum, an average of 24.6 lecture hours and 60 faculty-guided laboratory hours of instruction were offered. The number of laboratory hours in the last year of the old curriculum dropped to 39 hours due to a shortening of the length of laboratory sessions from 3 to 2 hours and one histology topic, Skin/Integumentary System histology, not being offered (Table 2). Despite several histology topics no longer being offered in the new UMMS medical curriculum (eye, ear, and skin histology), the average number of lecture hours increased slightly to 26.6 (Table 2). This was due to the incorporation of the half an hour lecture-style laboratory introductions, which were previously a component of the laboratory session. However, not all M1 sequences scheduled enough time for these laboratory introduction presentations. The length of lecture time reserved for histology instruction was not significantly different between the old and the new UMMS medical curriculum ($t(7) = 1.72$, $P = 0.13$; Table 2). Except for 6 laboratory session hours shared with the UMMS pathology instructors in the academic year 2016–2017, no formal faculty-guided laboratory instruction was offered to students in the new UMMS medical curriculum.

In the old UMMS medical curriculum, 9 to 12 different lecturers gave formal histology lectures (Table 2). Students' lecture evaluation mean rose in the new curriculum (M = 4.41, ±SD = 0.01) compared with the old curriculum (M = 3.96, ±SD = 0.24). Notably, only two faculty members delivered all the histology lecture presentations in the new curriculum. Compared with the old curriculum, this indicated a significantly higher rating of histology lectures by medical students ($t(6) = 4.72$, $P = 0.005$; Table 2). For the 2016–2017 academic year, the rules for students' lecturer evaluations were changed. Therefore, this year was excluded from the above analysis.

Students' attitudes toward learning histology

The survey offered to students at the end of their respective M1 histology component asked for their opinion on the importance of histology for their professional career as physicians. A statistical analysis indicated that students in the new curriculum viewed histology as an important component of their medical education significantly more than student in the old curriculum ($\chi^2 = 14.11$, $P = 0.0028$; Table 3). Students were also asked how they valued examination points derived from histology questions. The average scores on a five-point Likert scale for students in the old curriculum versus students in the new curriculum indicated no statistically significant difference ($\chi^2 = 1.27$, $P = 0.7367$; Table 3).

TABLE 3 Students' attitudes, motivation, learning strategies, and use of supplemental resources for histology in the old versus the new University of Michigan Medical School curriculum

	Old medical curriculum (2013–2016)						New medical curriculum (2018–2019)						
Question/statement	*N*	Very relevant to future career (%)	Quite relevant to future career (%)	Moderately relevant to future career (%)	Of minor relevance to future career (%)	Not at all relevant to future career (%)	*N*	Very relevant to future career (%)	Quite relevant to future career (%)	Moderately relevant to future career (%)	Of minor relevance to future career (%)	Not at all relevant to future career (%)	Statistical analysis *P*-value
How relevant do you think the M1 histology content is to your future career as a physician?	439	9.34	23.69	42.60	22.32	2.05	113	20.35	29.20	34.51	15.04	0.88	0.0028[a]
	N	Top priority	Second priority	Third priority	Fourth priority	Not a priority at all	*N*	Top priority	Second priority	Third priority	Fourth priority	Not a priority at all	
How did you value histology points compared with points from other disciplines?	438	10.50	39.73	35.84	10.73	3.20	113	6.19	29.20	41.59	18.58	4.42	0.7367
	N	Always	Frequently	Moderately	Rarely	Never	*N*	Always	Frequently	Moderately	Rarely	Never	
How frequently did you use the following study habits over the course of the academic year?—Study of histology by yourself	438	59.13	34.02	4.79	2.05	0.00	113	53.10	36.28	7.08	3.54	0.00	0.4882
How frequently did you use the following study habits over the course of the academic year?—Study of histology with others	438	2.28	7.08	14.61	39.27	36.76	113	0.88	11.50	15.04	38.05	34.51	0.5162
	N	Always	Frequently	Moderately	Rarely	Never	*N*	Always	Frequently	Moderately	Rarely	Never	
Attending histology lectures in-person	439	17.31	19.82	15.03	28.70	19.13	113	8.85	22.12	15.93	30.09	23.01	0.2722
Streaming histology lectures online	438	27.63	23.06	14.61	25.57	9.13	113	30.97	36.28	14.16	10.62	7.96	0.0037[a]
	N				Yes	No	*N*	Yes	No				
Prior to entering medical school, did you have any exposure to histology or pathology?	438				27.85	72.15	113	39.82	60.18				0.016[a,b]

Note: The following data are presented: Students' attitudes and motivation for learning histology, as well as their learning strategies, use of supplemental learning resources and previous exposure to histology/pathology in the old versus the new UMMS curriculum. [a]Significant *P*-values. *P*-values were calculated using chi-squared or [b]Fisher exact tests (two-sided).

Students' study approaches and use of resources for learning histology

Preference for studying histology alone or in a group exhibited no statistically significant difference between students in the old versus the new curriculum (studying alone: $\chi^2 = 2.32$, $P = 0.4882$, studying with others: $\chi^2 = 3.25$, $P = 0.5162$; Table 3).

Students' preference for attending in-person histology lectures was not significantly different for students in the old versus new medical curriculum ($\chi^2 = 5.15$, $P = 0.2722$; Table 3). However, students' preference for consuming histology lecture videos significantly increased for students in the new curriculum compared with students in the old curriculum ($\chi^2 = 15.52$; $P = 0.0037$; Table 3).

Students in both curricula were asked to estimate their study time for each histology topic (excluding lecture and laboratory session times). Overall, a majority of students in both the old and the new medical curriculum indicated that they studied between 1 and 3 hours per histology lecture topic (Figure 1). However, students in the old curriculum were significantly more likely to study histology for greater than 3 hours compared with students in the new curriculum ($\chi^2 = 49.25$, $df = 2$, $P < 0.001$, LR = 41.5). Correspondingly, students in the new curriculum were more likely to indicate that they studied for less than an hour per lecture topic (Figure 1).

Most students in the old UMMS medical curriculum chose to use the Michigan Histology website (UMMS, 2021) independently, never or rarely attending the scheduled histology laboratory sessions (Figure 2). Only a minority of students in the old curriculum frequently or always attended these sessions during which they had the opportunity to interact with histology faculty members. As shown in Figure 2, fewer students in the new curriculum made regular use of this resource and about one quarter of the class reported that they never used the Michigan Histology website.

In addition to devoting less time to studying histology and decreased use of the Michigan Histology website, other supplemental histology learning resources offered to students (Holaday et al., 2013) were also used less frequently and by fewer students in the new curriculum (data not shown).

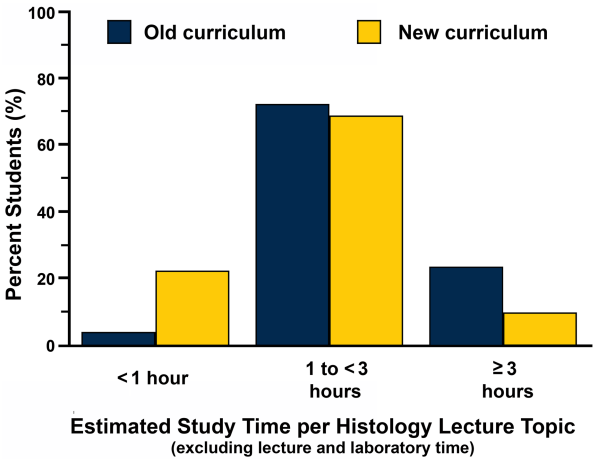

FIGURE 1 Time used by students for studying each histology lecture topic. Students were asked to estimate the time they used for studying each histology lecture topic, excluding lecture and faculty-guided laboratory time. The blue columns show the distribution of answers for first-year medical (M1) students from 2013 to 2016 in the old curriculum ($N = 436$), and the yellow columns show the distribution of answers for M1 students 2018–2019 in the new curriculum ($N = 113$)

Students' general academic performance for histology in the old versus the new UMMS curriculum

The number of quiz and examination questions per topic was guided by the number of scheduled teaching contact hours. Consequently, the introduction of the new UMMS curriculum resulted in a

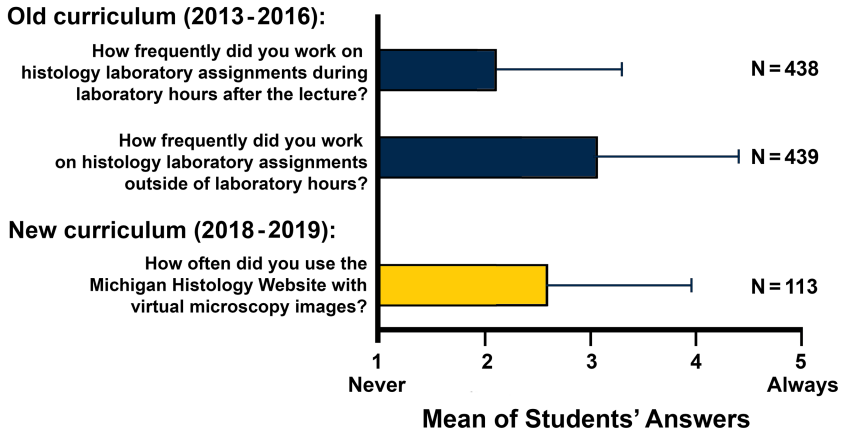

FIGURE 2 Participation in histology laboratory work by students in the old (top two bars) versus new curriculum (single bottom bar). Students in the old curriculum were asked how frequently (from never to always) they attended faculty-guided histology laboratory sessions (top bar) and/or worked with the Michigan Histology website on their own time (middle bar). Students in the new curriculum did not have to option to attend faculty-guided laboratory sessions and were only asked for their use of the Michigan Histology website on their own time (bottom bar). The bars represent the means (±SD) of students' answers based on a 5-point Likert scale ranging from 1 = never to 5 = always

significant reduction in quiz and examination questions for histology. Overall, students were asked an average of 1950 questions across all content areas on quizzes and exams in the old curriculum and 1926 in the new curriculum (Table 1). Thus, the overall number of quiz and examination questions in the M1 year for the old and new curricula was not significantly different ($t(3) = 0.92$, $P = 0.53$). In the old curriculum (2010–2016), an average of 175 histology examination questions were asked (representing 9% of all M1 questions), whereas the average number of histology questions decreased to 67 in the new curriculum (2016–2019, 3.5% of all M1 questions, Table 1), which represents a highly significant change ($t(7) = 11.29$, $P = 0.0017$).

Students' average cumulative examination score for all M1 subjects were not significantly different for the last two years of the old curriculum ($M = 89.86\%$, $\pm SD = 0.56\%$) compared with the first three years of the new curriculum ($M = 89.98\%$, $\pm SD = 0.33\%$), *t*-test $t(3) = 0.28$, $P = 0.81$. (Table 1). In contrast, the average cumulative histology score in the old curriculum (academic years 2010–2016) was 87.73% ± 1.04% compared with 81.15% ± 1.34% in the new curriculum (academic years 2016–2019), a highly significant statistical difference ($t(7) = 7.45$, $P = 0.004$). Under the old curriculum, an average of 2.3 ± 1.0 students (about 1.4% of each class) ended their M1 year with a cumulative histology examination score of <75%, which was categorized as a substandard performance (Hortsch & Mangrulkar, 2015). In the new curriculum, an average of 36.3 ± 3.1 students or 21.4% of each class completed their M1 histology component with a cumulative examination score below 75%, a highly significant increase ($t(7) = 18.75$, $P = 0.0017$; Table 1).

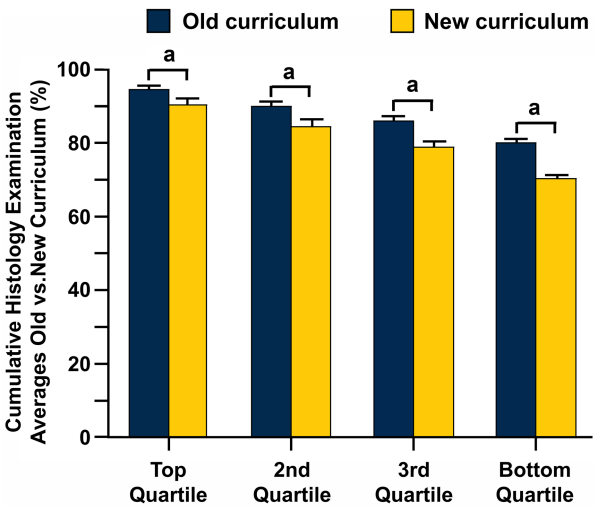

FIGURE 3 Comparison of the first-year medical (M1) histology cumulative examination averages between the old and the new curriculum stratified by class quartiles. The cumulative histology examination averages in percent are shown for each of the class quartiles. The blue columns represent students in the old curriculum ($N = 1009$; academic years 2010–2016), and the yellow columns represent students in the new curriculum ($N = 511$; academic years 2016–2019). *P*-values were calculated using a two-way ANOVA test with Bonferroni's multiple-comparison correction. [a]*P*-values of <0.0001

This decline of class cumulative histology scores from the old to the new medical curriculum did not affect all students evenly (Figure 3). The decrease in the cumulative histology score was highly significant for all four quartiles of histology performance, but the differences were smaller for the higher-performing quartiles (4.1% for the top quartile and 5.5% for the second quartile) and larger for the two lower-performing quartiles (7.1% for the third quartile and 9.7% for the bottom quartile).

DISCUSSION

The analysis presented in this article uncovered a significant decline in students' histology performance that coincided with the introduction of a new curriculum at the University of Michigan Medical School and the discontinuation of histology laboratory sessions. It is well documented that the academic performance of preclinical medical students in their histology component is influenced by a number of different factors, including but not limited to previous knowledge of the material (Forester et al., 2002; Helle et al., 2010; Selvig et al., 2015), the quality of didactic instruction and resources (Helle et al., 2013), availability of and student engagement with educational resources (Smirle et al., 2012; Zureick et al., 2018), student motivation (Selvig et al., 2015), and attendance of didactic sessions (Selvig et al., 2015). A number of these aspects and variables were investigated in this study to identify the factors that may have contributed to the observed drop in medical students' histology performance.

Several variables that may have influenced the change in students' M1 histology performance can likely be eliminated. The overall and science undergraduate GPAs for incoming UMMS M1 classes were indistinguishable between the two curricula, indicating that the academic preparedness of incoming UMMS medical students did not change during the curricular transition (Table 1). Similarly, no statistically significant difference was found for the cumulative class averages for all subjects during the M1 year. Only students from one M1 class in the new curriculum were sampled about their previous exposure to histology. A significantly higher number of M1 students in the academic year 2018–2019 reported that they had prior histology experiences. As several reports indicated that previous histology experiences are correlated with higher M1 histology performance (Forester et al., 2002; Selvig et al., 2015), this finding should have counteracted the reported decline in the histology class performance.

The cumulative number of histology lecture hours remained approximately the same in the new curriculum, despite several topics no longer being covered (Table 2). One other notable change was the transition from a team-taught (9 to 12 lecturers) to an individually taught (one to two lecturers) histology lecture component. Comparing team-taught with individually taught courses, the published literature provides no consistent conclusion on whether team-taught or individually taught instruction is superior to the other (Dugan & Letterman, 2008; Jones & Harris, 2012; Money & Coughlan, 2016; McDonald et al., 2021). The majority of histology

lectures in the new UMMS curriculum were given by one of the two instructors, a lecturer, who had previously received the highest lecture evaluations in the old curriculum. Thus, the increase in student evaluation scores for histology lectures in the new curriculum (Table 2) was at least partially driven by students' preference for a specific lecturer. Even though student lecture evaluations provide an incomplete indicator of didactic lecture quality (Stitik et al., 2002; Emery et al., 2003), using this information as a loose proxy suggests that the observed decrease in histological performance is not related to lecture quality.

As reported in several recent publications, curricular changes can have a significant impact on students' study and learning strategies for the anatomical sciences (Thompson & Lowrie, 2017; Husmann et al., 2020). However, no significant changes were found for several such variables when comparing UMMS M1 students in the old versus new medical curriculum. Students continued to prefer to study alone, rather than in groups (Holaday et al., 2013; Selvig et al., 2015). In person attendance of live lectures was relatively low in both the old and new curricula (Table 3). Only the consumption of lecture video recordings was slightly increased in the new curriculum, a trend that has previously been reported (Zureick et al., 2018).

The traditional two components of histology education, lectures and laboratory sessions, have connected, but generally different, learning objectives. The first teaches the scientific facts about the structure of cells and tissues, whereas the second helps students develop their visual analytic skills and requires them to correlate their observations with what they learned in the didactic portion of their histology course (Drake et al., 2002; Koury et al., 2019). The interpretation of histological images can be considered a higher-level learning task in the context of Bloom's taxonomy (Zaidi et al., 2017). Both aspects are considered necessary for acquiring proficiency in histology (Das et al., 2019). A major change that accompanied the introduction of the new UMMS medical curriculum was the lack of scheduled faculty-guided laboratory sessions. As attending these sessions was not compulsory in the old UMMS curriculum, only a minority of students regularly participated (Holaday et al., 2013). However, students who did attend scored significantly better when answering M1 histology questions (Selvig et al., 2015). As scheduled time for histology laboratory sessions was an integral part of the old curriculum schedule, students were able to work on their histology laboratory assignments independently using the Michigan Histology website (UMMS, 2021). In the new curriculum, no time was scheduled for histology laboratory education, and students had to decide when and how much time to set aside for these learning exercises. This likely contributed to the significant reduction in student time dedicated to histology learning (Figure 1). Although a majority of students in the new curriculum still report 1 to 3 hours of study time for each histology lecture topic, significantly fewer students reported using more than 3 hours, and many more students used less than 1 hour compared with M1 students in the old curriculum. The finding that basic science laboratory experiences for medical students boost learning outcomes is not unique to the anatomical sciences. A recent study by Lawson et al. (2020) reported similar findings for student participation in voluntary microbiology laboratory sessions, a topic that has also seen significant reductions of instruction time in more recent medical curricula (Hearing & Lu, 2014).

Specific statistical comparisons regarding how students used the laboratory resources was not possible because of differences in survey questions. Students in the old curriculum were asked how often they studied laboratory materials during histology laboratory sessions versus outside these laboratory sessions. As there were no laboratory sessions scheduled in the new curriculum, there was no directly analogous comparator. Students in the new curriculum did have access to the Michigan Histology website (UMMS, 2021), and they were asked how often they used it. Although the data suggest a reduction in website usage, the qualitative nature of the first question and the quantitative nature of the second does not allow for direct head-to-head statistical analysis.

Corresponding to the reduced number of contact hours for the teaching of histology, fewer histology questions were asked on M1 quizzes and examinations (Table 1). As a result, the proportion of histology questions asked on M1 assessments declined more than twofold. Nevertheless, students in both curriculum settings equally valued points rewarded for M1 histology examination questions (Table 3).

Formative feedback has been identified as another important factor for students' learning success and the development of professionalism in the anatomical sciences (Camp et al., 2010; Youdas et al., 2013), as well as for the identification of students struggling with histology (Hortsch and Mangrulkar, 2015). Therefore, whether histology subscores were regularly provided to M1 students may have played a role in individual and class scores for histology. During the first year that histology was taught using the new curricular framework (academic year 2016–2017), students no longer received regular subscores for their histology performance. However, students falling below the 75% of marks were informed by the Academic Review Board, and they were encouraged to contact the histology discipline director (M.H.) for advice on how to improve their performance. In the academic year 2017–2018, this practice was discontinued. It is possible that being unaware of one's performance in specific disciplines, such as histology, may have made it difficult for students to self-identify areas for improvement. Consequently, the observed difference in the performance between students in the two curricular frameworks may be partially explained by differences in communicating learning outcomes to students. More recently with the introduction of a new outcomes management system, UMMS students are again being provided with subject subscores.

It is reasonable to assume that medical education reforms will continue to be implemented in rapid succession. As an increasing number of novel technologies and scientific approaches are constantly being introduced into modern medicine, medical educators will have to grapple with difficult decisions surrounding what scientific knowledge and skills will be required of tomorrow's physicians (Woolliscroft, 2019). As a strong scientific foundation remains the starting point for the education of all health care professionals, the basic sciences, including histology, should continue to be a

fundamental component of preclinical curricula (Slivkoff et al., 2019). However, their place in these curricula will be evolving and novel teaching strategies may need to be tested and adapted, as some traditional didactic approaches might not be best suited for modern medical education. A first step in redefining the role of histology in the education of future medical doctors is the compilation of a list of basic competencies, knowledge, and skills medical and other health science students are expected to acquire. Two recent publications now provide such lists for the field of medical histology (Das et al., 2019; Cui & Moxham, 2021).

Furthermore, histology educators will need to discuss with their learners, colleagues, and university administrators which traditional histology skills are still appropriate for today's medical learners. For instance, there is an ongoing discussion about whether optical microscopy skills should still be taught to all medical students (Pratt, 2009; Hortsch, 2013; Kuo & Leo, 2019). This conversation will need to be extended to other aspects of histology. As a suggested starting point, perhaps educators should discuss whether the analysis and interpretation of microscopic images (as was traditionally taught in histology laboratories) should still be incorporated into the general education of physicians and dentists, or if these specialized skills should be taught only to specific subgroups of learners, such as future pathologists.

By providing a cell-based description of human tissues and organs, histology is intricately linked to many other basic sciences, specifically physiology, biochemistry, embryology and its own modern version, cell biology. On Step 1 of the United States Medical Licensing Examination® (USMLE®), histology and cell biology are already tested together. Many modern medical curricula connect histology instruction with the teaching of its clinical counterpart, pathology (Kumar et al., 2006; McBride & Prayson, 2008). Histological knowledge is a positive predictor for students' performance in pathology (Nivala et al., 2013). Thus, the combination of classical histology with other basic sciences and clinical disciplines appears to be a promising path for the benefit of medical students (Sherer et al., 2014; Lu et al., 2016; Cheng et al., 2020). At the curricular level, discontinuing standalone histology courses and integrating them with the other basic sciences have been an ongoing effort for more than a decade. Some medical schools adopted this strategy early on (Drake, 1998; Klement et al., 2011; Scheffer et al., 2012), whereas others, especially in developing countries, have done so more recently or are still in the planning phase of introducing a truly integrated pre-clinical curriculum (Jonassen et al., 2016; Lu et al., 2016; Yohannan et al, 2019). The new curriculum at the UMMS represents a new round of curricular changes, further consolidating time spent on teaching the basic sciences (O'Connor Grochowski et al., 2007; Scudder et al., 2019; Daniel et al., 2020).

Other opportunities for adapting histological content to the modern curricular landscape are novel didactic methods, which include case- and team-based learning (Goldberg and Dintzis, 2007; McBride and Prayson, 2008; Ettarh, 2016; King et al., 2019), small group learning (Bloodgood, 2012), self-directed and online instruction (Khalil et al., 2010, 2013; Jurjus et al., 2018), and the flipped classroom strategy (Gilliland, 2017; McLean, 2018). All these approaches have been successfully used for histology instruction. However, integrating such strategies for histology instruction into time-restricted medical curricula will require continued discussion with all stakeholders and thoughtful implementation to ensure that it will remain beneficial for present and future generations of medical trainees.

Study limitations

As academic success in medical histology is influenced by a multitude of factors, such as the learning environment, teaching modalities, and didactic resources, the present study most likely has not tested and uncovered all variables that influence students' academic performance in the old versus the new UMMS curriculum. However, the combination of limited instruction and learning time scheduled for histology with the lack of hands-on histology laboratory sessions appear to be major factors.

Some of the data reported in this study were based on students' recall and self-reported data of their study habits during their M1 histology component. As comparisons between answers given to identical questions by different M1 classes using the same curricular framework showed relatively small year to year variations, the survey questions appear to provide a reliable, but not a perfectly precise quantitative representation of students' opinions and study behaviors.

Although the reported findings are most likely of general relevance and applicability, the UMMS learning environment has unique elements that may have impacted the reported results and may not be relevant at other schools. In addition, this article only investigates learning outcomes for a medical histology component, so care should be used when extrapolating these results to other subjects and student populations.

CONCLUSIONS

The analysis presented in this article demonstrates that curricular changes can have a significant impact on students' academic performance in histology. As histology instruction is traditionally based on two didactic modalities, lectures and laboratory work, both appear to be important for achieving a high level of competency for this discipline. The elimination or reduction of one of these two components has the potential to affect students' learning success. When limiting instruction time for histology, students will respond by allocating their learning efforts accordingly, possibly to the detriment of the learning outcome. Therefore, these consequences should be contemplated when designing or changing the basic science curriculum for medical students. Medicine is a field that increasingly relies upon the cellular and molecular features of disease for diagnosis and management. The medical students surveyed in this and in other studies indicated that they

believe histology still has a role in their education to become a practicing physician (Selvig, et al., 2015; Moxham et al., 2017), yet its representation in the curricular space has diminished and students' mastery of the subject has declined. Therefore, it is imperative that histology educators and learners together with curriculum administrators begin a robust discussion of whether and where traditional histological skills still fit in the practice of modern medicine.

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CONFLICT OF INTEREST

The authors report no conflicts of interest, and they alone are responsible for the content and the writing of this article.

ORCID

Michael Hortsch https://orcid.org/0000-0002-3750-737X

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AUTHOR BIOGRAPHIES

William Gribbin, M.Sc., is a fourth-year medical student in the class of 2022 at the University of Michigan Medical School in Ann Arbor, Michigan. He is interested in the intersection of emerging technologies, medical education, and clinical practice.

Eric A. Wilson, B.S., is a fourth-year medical student in the class of 2022 at the University of Michigan Medical School in Ann Arbor, Michigan. He has an interest in medical education and hopes to pursue a career in academic medicine that incorporates both research and preclinical/clinical teaching.

Suzy McTaggart, B.S., is an Assistant Director of Evaluation and Assessment at the University of Michigan Medical School in Ann Arbor, Michigan. She oversees the assessment efforts and programmatic evaluation of the preclinical phase of the medical curriculum. Her research interests include medical education and novel assessment modalities.

Michael Hortsch, Ph.D., is a professor in the Departments of Cell and Developmental Biology and of Learning Health Sciences at the University of Michigan Medical School in Ann Arbor, Michigan. Since 1991, he has taught medical and dental histology, and his main research interests are in the development of novel electronic teaching tools and how these resources impact students' learning.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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