What Faculty and Students Value When Evaluating Human Digital Anatomy Platforms: A Mixed-Methods Study

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ABSTRACT

OBJECTIVES: There is an increasing availability of digital technologies for teaching and learning of human anatomy. Studies have shown that such applications allow for better spatial awareness than traditional methods. These digital human anatomy platforms offer users myriad features, such as the ability to manipulate 3D models, conduct prosection, investigate anatomical regions through virtual reality, or perform knowledge tests on themselves. This study examined what faculty members' value when using digital human anatomy platforms for teaching and what students value when using these platforms for learning.

METHODS: Six anatomy faculty members and 21 students were selected to participate in this study. After using the three digital anatomy platforms for at least 1 week, a survey was conducted to record their feedback in 4 categories: usability, interactive features, level of detail, and learning support. Respondents' Qualitative feedback within each category was also analyzed to strengthen the study's findings.

RESULTS: The study's findings showed that faculty members and students have different priorities when evaluating digital anatomy platforms. Faculty members valued platforms that provided better accuracy and detailed anatomical structures, while students prioritized usability above the rest of the features.

CONCLUSION: Given that faculty and students have different preferences when selecting digital anatomy platforms, this article proposed that educators maximize the specific affordances offered by the technology by having a clear pedagogy and strategy on how the technology will be incorporated into the curriculum to help students achieve the desired learning outcomes.

KEYWORDS: human digital anatomy, 3D anatomy, human gross anatomy, technology-enhanced learning, anatomy education

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Introduction

Dissection has been the primary teaching method for anatomy for the past few centuries. Learning using the dissection of human cadavers has advantages that are not easy to quantify, such as enhancing active and deep learning, providing vital three-dimensional perspectives of anatomical structures,[1] preparing students for clinical practice by getting acclimatized to cutting the human body,[2] preparing students for encounters with death, the practice of manual skills and for understanding the relationship between patients' symptoms and pathology.[3] However, changes in pedagogy and technological advancements have shown that anatomy education based on dissection is declining.[4,5]

The current education approach is increasingly shifting from a teacher-centered to a student-centered approach, where the student's voice plays a central role.[1] This approach encourages students to be responsible for their learning instead of passively receiving information. A student-centered approach is guided by the aim to facilitate skill acquisition rather than route memorization of concepts, and where teachers are no longer seen as the sole source of knowledge but function as a guide.[6,7] To do so, students must be given the tools to take ownership of their learning while the teacher guides them toward mastering the required skills. This is where technology can help complement time spent learning human anatomy using a blended approach.[8]

The need to complement traditional instruction with technology is further pertinent to understanding the nature of the anatomy subject, which makes learning this subject so difficult. The large amount of surface knowledge in learning anatomy proves highly cognitively demanding to students,[9,10] who struggle to cope with a deep understanding of content and knowledge transfer.[11] It follows then that technology, the "overwhelming learning tool of today,"[12(p19)] be utilized to facilitate a more profound learning process for students. The

value of technology, such as virtual dissection programs, scans, and 3D modeling[13]—lies in its ability to visualize hidden structures three-dimensionally,[14] showcasing anatomy in a living and undamaged state without unintentional damage from dissection or the effects of embalming chemicals used on cadavers,[15] with the added benefit of circumventing ethical concerns.[16,17] Anatomy instruction should be guided by the aim of leaving students with a deep functional understanding of anatomy over a comprehensive one, and thus, anatomy teaching must be up to date and integrated with current medical approaches that utilize technology for teaching anatomy.[18]

Over the past 10 years, there has also been an increase in studies investigating the use of technology in anatomy teaching.[19–21] Many e-learning resources have been used to augment conventional anatomical teaching methods.[22] Educators are constantly adapting their teaching strategies[23] to evolve based on the latest findings in education research,[24] such as using virtual reality,[25,26] 3D printing,[27,28] and digital learning resources.[29,30] While dissection remains the gold standard, Johnson and colleagues suggest that no single method for teaching anatomy is supreme over another.[31] With the availability of a myriad of tools for teaching anatomy, selecting the appropriate platform to be used in institutions benefits from evaluative feedback from clinical faculty who are subject matter experts but not necessarily pedagogical experts. This was shared by McLachlan et al,[32] and Petersson et al[4] believe that further evaluation of educational tools based on living anatomy, virtual reality, and imaging techniques is required.

However, few studies have evaluated different digital anatomy platforms from both faculty and students' perspectives. For example, past studies investigated students' perception of learning using virtual reality in Unity gaming platform,[33] compared students' perceptions of using augmented reality versus traditional classroom tools for learning skull anatomy,[34] perception of using MagicBook, a mobile augmented reality platform for learning neuroanatomy.[21] Only one study was found on various commercial and non-commercial digital learning platforms.[35] Still, the comparison was made by only two faculty members who served as experts in rating the different platforms.

To bridge the gap in the literature, this paper covers the results of the evaluative survey completed by students and faculty, and results can be understood theoretically using the concept of judgments of learning (JOLs), which relates to how digital learning resources are evaluated, especially by both faculty and students. Literature on JOL is relatively unified in its consensus that students' metacognitive perceptions of learning are weakly or negatively correlated with their actual learning, as measured by their test performance.[36] This speaks to illusions of learning[37]—a subset of JOL that sees students misinterpreting various factors in their learning process as indicators or cues of successful learning.

Perceptions of learning include perceived instructor fluency and effectiveness[37] and mental effort expended on learning.[38] These perceptions impact how well the students think they will perform on tests or how confident they feel, thus being a subjective judgment of learning. For example, an instructor who speaks fluently, uses non-verbal gestures and pauses, and speaks with a dynamic vocal intonation influences students into thinking the educator is much more effective than another "disfluent" instructor who speaks haltingly, monotonously, and rarely makes eye contact.[39] However, students taught by the fluent instructor did not fare any differently than those taught by the disfluent instructor when assessed by a memory test. This highlights an illusion that learning is perceived to be more effective in an environment that subjectively feels better or easier.

Being perceptions, these "learning cues" are by nature subjective and not always rooted in sound theoretical understanding or evaluative tools.[40] Hence, students' JOLs are often inaccurate as they represent their heuristics, cognitive biases, and selective memory lapses more than their actual learning.[37]

Research questions

1. What are the differences between how faculty and students evaluate digital human anatomy platforms?
2. What do faculty and students value when choosing a digital human anatomy platform for teaching or learning?

Methods

Selection of human digital anatomy platform

To evaluate existing commercially available digital human anatomy learning tools, an initial shortlist was made of commercial systems that resulted in six anatomy learning platforms, namely: 3D Organon,[41] Visible Body®,[42] BioDigital,[43] Zygote Body®,[44] Complete Anatomy,[45] and Primal Pictures.[46] These were selected based on a range of features, functionality, ease of access, and scope for further development.

A detailed evaluation was then conducted by the authors in May 2020 with input from Anatomy faculty members across three categories: interactive features (9 criteria), anatomical model details (2 criteria), and learning support (7 criteria). "Interactive features" refers to software features within the platform, such as if it has AR or VR capabilities, supports real-time collaboration, contains multiple health conditions, cross-sectional views, navigational tools, complete digestive system model, look and feel personalization, and makes annotations to share models with others. "Anatomical model details" refers to the level of detail of the anatomical models and if

the platform features life-sized 3D models. "Learning support" refers to other pedagogical affordances within the platform, such as the ability to personalize the look and feel of the platform, 3D animation, the ability to develop learning materials for students, importing external files into the system, cloud-based platform, the ability to create quizzes, and 3D printing capabilities. This resulted in a further shortlist (Visible Body, Complete Anatomy, and Primal Pictures) evaluated through a usability and features survey.

The authors evaluated 6 digital human anatomy platforms and the features they believed were essential to be part of the evaluation process based on existing literature[3,17,29,33,35,47,48] and their (JS and FB) expert opinion. The purpose is not to promote one human anatomy platform over another but to understand the preference for faculty members teaching and students learning anatomy. Table 1 summarizes the features of the 6 digital human anatomy platforms initially compared by the authors' JS and FB in early 2020. Each platform has its unique offering that may only sometimes be available on another platform.

Based on the initial comparison of the digital anatomy platforms and recommendations from faculty members, we narrowed down three digital human anatomy platforms for further evaluation by faculty and students. These platforms are Primal Pictures, Visible Body, and Complete Anatomy, where a full-featured 30-day trial license was obtained.

Study participants

This study occurred at a graduate medical university in Singapore. Students were enrolled in the Doctor of Medicine (MD) Program and have completed their first basic degree. Each cohort has up to 72 students. The 4-year program consists of a 1-year pre-clerkship where the basic sciences are taught, a 1-year Clerkship followed by a 1-year Research and Scholarship, and the final year of Advanced Clinical Rotations.

This study used a purposive sampling approach in data collection. Only faculty members teaching human anatomy and medical students who have completed the human anatomy course were included in the study. Exclusion criteria were non-anatomy faculty, non-medical students, or those who did not provide their informed consent to participate in the study. Fourteen faculty members involved in teaching human anatomy, such as the anatomy leads for different organ systems, physiology lead, and radiology lead, were invited to participate in the survey. However, only 6 faculty members responded to the survey questionnaire. For the students, 21 out of 28 students recommended by the Anatomy Faculty Lead participated in this study. These students consist of 10 in Year 1, 6 in Year 2, and 5 in Year 3.

The Learning and Analytics Committee on Ethics, National University of Singapore (Approval Ref: L2020-12-01) classified this study as exempt. Data for this study were collected in July 2020 and distributed through Qualtrics XM.[49] Written informed consent was obtained from all respondents to include their survey feedback in this study.

Analysis

Statistical analysis was done using IBM SPSS for Mac[50] version 29. Descriptive statistics were used to summarize and present the faculty and students' responses to the questions. The mean scores and standard deviations were calculated for each survey dimension to compare faculty and student perceptions of learning platforms.

Quantitative data. Respondents were given 30-day access to the three shortlisted human anatomy platforms (Visible Body, Complete Anatomy, and Primal Pictures). A survey was sent out a week later, and participants could complete the survey anytime within the trial period. The purpose of the survey is to obtain feedback from respondents on their familiarity with each platform and for them to rate their satisfaction with using the platforms across 4 categories, namely: usefulness (4 questions), interactive features (7 questions), level of detail (3 questions) and learning support (4 questions), with an option to provide further clarification on their ratings. The survey also collected other data, such as the approximate time spent evaluating the platforms, prior experience using the platforms, and ranking preference, with reasons for the 3 platforms.

The categorization of survey questions was based on a review of the literature and existing surveys. The category usefulness refers to the overall usefulness of the platform and consists of 4 questions: overall usefulness to support anatomy learning/teaching; ease to understand and to learn to use; meeting needs for learning/teaching anatomy; and demonstrating sufficient detail for anatomy learning. Interactive features consisted of 7 questions: ease of navigation; quality, usefulness, and range of health conditions module; usefulness and quality of cross-sectional view; ease of use and quality of visualization features; ability to customize the look and feel; usefulness of personal list of 3D models; and usefulness of markup and sharing of 3D models. The level of detail consisted of 3 questions and referred to the overall accuracy of the anatomical models; the overall level of detail provided, and the ability to display and explore different layers or components of organs of interest. Learning support consisted of 4 questions that measured respondents' opinions on the usefulness, quality, and range of lectures, 3D animation of anatomy-specific topics, ability to share anatomical models using the tools provided, usefulness of the quiz features, and ease of use, functionality, and completeness of the mobile app.

Qualitative data. Respondents could provide qualitative feedback on their responses after rating their agreement with each category through an open-ended question. If respondents provided qualitative feedback, the authors (JL, JS, TL) would read through the

Table 1. Comparison of features of the human digital anatomy platforms.

	3D Organon	Visible Body	BioDigital	Zygote Body	Complete Anatomy	Primal Pictures
Interactive Features						
VR Ready	√		√		√	√
AR Ready		√				√
Real time collaboration	√					√
Multiple Health Conditions		√	√		√	√
Cross-sectional views		√			√	
Navigation tools	√	√	√	√	√	√
Digestive system model	√	√	√		√	√
Look and feel personalization		√	√		√	√
Markup and share 3D models			√	√	√	√
Anatomical Model Details						
Level of details	Mid	Mid	High	High	High	Mid
Life sized models	√					√
Learning Support						
Personalization		√	√		√	
3D Animation			√		√	
Develop materials for students		√	√		√	√
Import external files					√	
Cloud Based		√	√		√	√
Quiz	√	√	√		√	√
3D Printable				√		

Table 2. Faculty and students familiarity with the digital human anatomy platforms.

	Primal Pictures		Visible Body		Complete Anatomy	
Familiarity	Faculty % (*n*)	Student % (*n*)	Faculty % (*n*)	Student % (*n*)	Faculty % (*n*)	Student % (*n*)
Not familiar	83 (5)	100 (21)	83 (5)	76 (16)	66 (4)	4 (1)
Somewhat familiar	17 (1)	0	17 (1)	24 (5)	17 (1)	36 (7)
Very familiar	0	0	0	0	17 (1)	60 (13)

comments and include these comments if they could clarify or provide good illustrations to support findings and discussion.

Results

Familiarity with the platform

Most faculty were unfamiliar with the three digital human anatomy platforms surveyed, and the institution had yet to subscribe to them. Among the three platforms, faculty and students were least familiar with Primal Pictures, while more than half of the students surveyed were very familiar with Complete Anatomy. Table 2 summarizes the respondents' familiarity with the learning platforms.

Faculty and student satisfaction and feedback on the platforms

This section will present the findings from the survey data collected from the respondents. The findings will be based on usability, interactive features, level of detail, and learning support on a scale of 0 to 100. Open-ended qualitative feedback from respondents in each category will support the quantitative findings of this section.

Usability. Four questions were asked to understand the usability of the platform to support learning. The first question was to understand the perception of the overall usefulness of the software for anatomy teaching or learning. Faculty rated Primal Picture's overall satisfaction at 75, Visible Body (60), and Complete Anatomy at 53. Students found both Visible Body

and Complete Anatomy most useful for learning (74), followed by Primal Pictures (68). When asked how easy it was to use the three platforms, faculty rated all three platforms between 55 and 58, while students rated Complete Anatomy the highest (78), Visible Body (72), and Primal Pictures (58). When asked how well the platform meets their teaching or learning needs for anatomy, faculty rated Primal Pictures the highest (72), followed by Visible Body (58) and Complete Anatomy (50). However, the opposite was true for students who rated Complete Anatomy (73) and Visible Body (71) the highest, followed by Primal Pictures (66). When faculty were asked to rate the platforms in terms of the level of detail, Primal Pictures was rated the highest at 82, followed by Visible Body (63) and Complete Anatomy (57). However, students were generally satisfied with all three platforms, with ratings between 77 and 79.

Based on the qualitative feedback, positive comments did not differ across all three platforms, with some students citing that all the platforms had helpful features and had good ease of use. However, this qualitative feedback was not homogenous across the wide range of responses, and the negative or critical sentiments noted from other responses were that all the platforms had some degree of usability issues. Additionally, Complete Anatomy was reported to have a poor level of detail. From the faculty's responses, Primal Pictures was said to have helpful features, detail, and a good level of amenability within the app, and the negative sentiment was that Primal Pictures was difficult to learn. Complete Anatomy was positively reported to have useful content, although it was also difficult to use. Visible Body was positively reported to have useful functions and being easy to use.

Among the reasons that Primal Pictures was lower in terms of usability, as noted in the quantitative data, could be attributed to its User Interface being too complex to accommodate a broader range of features. In addition, the platform also requires an active internet connection, and there needs to be more intuitiveness when navigating the platform. While students acknowledged that Complete Anatomy does not have as much content as the other platforms, they shared that Complete Anatomy was easy to learn, smooth, and had seamless navigation with a clear layout, capable of annotation and adding their notes, making it the highest rated satisfaction in terms of usability. These results are reflected in Table 3.

Overall, faculty were more in favor of Primal Pictures regarding usability. One faculty member highlighted that 3D models in Primal Pictures could be "flanked by diagnostic imaging of the same anatomical district" that aids student learning on pathological anatomy and associated symptomatology (Faculty 2). Another faculty member shared that Primal Pictures has the most "balance between being user friendly and accurate," highlighting the importance of overall features when evaluating anatomy tools (Faculty 3). Another faculty member (Faculty 6) acknowledged that Primal Pictures can be "daunting for students" and pointed out that the video lectures in Complete Anatomy would benefit students.

Interactive features. Interactive features refer to the quality of interactive features within the platform. These questions aimed to understand how faculty members and students perceive the affordances within the various platforms for their teaching and learning needs. Across all seven questions, faculty members rated Primal Pictures most favorably among the three platforms, while students were mixed in their ratings between Visible Body and Complete Anatomy. Students found Complete Anatomy to have better navigation-related features, visualization features, and the ability to customize the look and feel. In contrast, Visible Body had better quality and a range of features for health conditions and the ability to "capture, mark-up, and share images." The results are reflected in Table 4.

The feedback from the students' responses for Primal Pictures was that the platform had poor usability in its features meant to support learning and lacked essential features. For Visible Body, a common feedback was that it had many unnecessary features, though some were also beneficial for learning. For Complete Anatomy, a lack of features was commonly noted, as well as how the app offered users a good level of customization. Faculty did not comment much on the interactive features of the applications, although one respondent noted that the features in Primal Pictures were useful and of good quality.

Level of detail. The purpose of the digital anatomy learning platform is to provide users with an immersive experience that allows them to explore virtual anatomical structures with a sufficient level of detail. Three questions were asked to measure the respondents' opinions on the "overall accuracy of the anatomical models," "overall level of details provided," and "ability to display and explore different layers or components of organs of interest." Among the three digital anatomy platforms, faculty members rated Primal Pictures the highest for all four questions, followed by Visible Body and Complete Anatomy (see Table 5).

Students had mixed opinions on the digital anatomy platforms regarding the level of detail. They felt that all three digital anatomy platforms provided good overall accuracy and overall level of detail of the anatomical models. When asked about the accuracy of the specific anatomical regions relevant to their learning, students rated Complete Anatomy highest (79), followed by Visible Body (73) and Primal Pictures (67). Regarding the usefulness, quality, and ease of use of the cadaveric images, students rated Visible Body at 69, followed by Primal Pictures (65) and Complete Anatomy (61).

The positive feedback noted from students' responses was that Primal Pictures was accurate, detailed, and had useful features, and these sentiments were shared among faculty.

Table 3. Faculty and students feedback on the usability of the platforms.

	Primal Pictures		Visible Body		Complete Anatomy	
	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)
Overall usefulness to support anatomy teaching/learning in the Duke-NUS MD Programme	75 (12)	68 (20)	60 (17)	74 (14)	53 (31)	74 (22)
How easy it is to understand and learn how to use?	58 (19)	61 (22)	58 (20)	72 (18)	55 (24)	78 (18)
How well does it meet your needs to support anatomy teaching/ learning?	72 (21)	66 (19)	55 (18)	71 (17)	50 (28)	73 (20)
How well does it demonstrate enough detail for anatomy teaching/ learning?	82 (12)	79 (11)	63 (15)	77 (13)	57 (25)	76 (19)

Response options on a 100-point scale with 0 = strongly disagree to 100 strongly agree. Average scores are expressed in means (±SD).

Table 4. Faculty and students feedback on interactive features of the platforms.

	Primal Pictures		Visible Body		Complete Anatomy	
	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)
Ease of navigation through human anatomy?	63 (14)	63 (18)	58 (16)	72 (18)	52 (24)	77 (21)
Quality, usefulness and range of health conditions module/feature?	67 (24)	66 (20)	55 (19)	71 (17)	50 (24)	62 (19)
Usefulness and quality of cross-sectional views?	80 (14)	73 (15)	60 (13)	69 (14)	55 (20)	68 (20)
Ease of use and quality of visualisation features such as pan, zoom in/ out and agile rotation?	77 (15)	68 (22)	68 (16)	79 (14)	65 (29)	83 (19)
Ability to customise look and feel of the anatomical models and visualisations?	68 (12)	60 (19)	55 (12)	70 (16)	47 (22)	72 (23)
Usefulness of the personal list of 3D models in dashboard?	67 (20)	56 (23)	53 (20)	60 (25)	52 (30)	61 (28)
Usefulness of the capture, mark-up, and share images of 3D models?	70 (17)	59 (22)	53 (16)	66 (21)	47 (23)	63 (24)

Response options on a 100-point scale with 0 = strongly disagree to 100 strongly agree. Average scores are expressed in means (±SD).

Similarly, Complete Anatomy was cited to be realistic, have useful features, and have a good level of amenability. Visible Body was again positively noted to be accurate, realistic, and clear in its illustrations. However, students noted that Primal Pictures was challenging to use, and both faculty and students indicated that its visuals were sometimes inaccurate and of poor quality. Students and faculty pointed out Complete Anatomy to lack functions, with students reporting a more inferior level of detail than other apps. Some students noted that Complete Anatomy content does not complement the anatomy curriculum in school. Both students and faculty said Visible Body lacks features and details, is too simplistic, and has poor visual quality.

One student shared that Primal Pictures and Visible Body have very good details for microanatomy. In contrast, another student found cadaveric images easily accessible and the most important feature for learning in Primal Pictures. Two students acknowledged that Complete Anatomy does not offer sufficient detail for microanatomy. However, this did not affect their rating of the platform. One of these students wrote:

> "…The Visible Body and P&P [Primal Pictures] app does the microanatomy sections very well, in detail, that the Complete Anatomy doesn't. For gross anatomy, I think the level of detail is similar in all 3, but it's easier to navigate the various layers in complete anatomy. However, Complete Anatomy doesn't do the head & neck anatomy very well, and the microanatomy also fares poorly." (Student 4)

Another student shared that Primal Pictures did not allow for the selection of different layers for the anatomy models, but this could be done in Complete Anatomy. This student

Table 5. Faculty and students feedback on the level of detail of the platforms.

	Primal Pictures		Visible Body		Complete Anatomy	
	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)
Overall accuracy of the anatomical models?	78 (12)	80 (14)	67 (15)	80 (14)	63 (23)	81 (18)
Overall level of details provided?	78 (8)	77 (14)	63 (12)	79 (14)	60 (21)	79 (19)
Ability to display and explore different layers or components of organs of interest	73 (14)	67 (20)	63 (14)	73 (18)	57 (23)	79 (19)

Response options on a 100-point scale with 0 = strongly disagree to 100 strongly agree. Average scores are expressed in means (±SD).

favored Complete Anatomy for this reason, stating that it was important to be able to select different layers:

> "It is important to be able to select the layers for the anatomical models. Complete anatomy allows me to select the specific layer that I would like to have present. I experienced issues with the layering of primal pictures as they are numbered instead of named. A user is unable to know which layer is added or removed unless they experiment via trial and error." (Student 14)

Learning support. Learning support refers to features that support students in their learning and faculty in their teaching. In their responses, participants noted features such as lecture or course videos on anatomy-specific topics, the ability to capture and share anatomical models, quiz functionality, and the mobile app. Among the three digital anatomy platforms evaluated, faculty members rated Primal Pictures the highest for all four questions on learning support, followed by Visible Body and Complete Anatomy.

Regarding the usefulness, quality, and range of lectures, 3D animation on anatomy-specific topics, students felt that Visible Body performed slightly better (67) than Primal Pictures (65). In comparison, Complete Anatomy was rated at 61. Students ranked Primal Pictures and Visible Body similarly at 62 for the ability to capture and share anatomical models, while Complete Anatomy was rated at 50. All the digital learning platforms also had a mobile app version, and students rated Complete Anatomy and Visible Body App the highest (74) in terms of ease of use, functionality, and completeness. In comparison, Primal Pictures was rated at 50.

In line with this, students' responses showed a negative perception that Primal Pictures and Visible Body had subpar features and poor usability and Complete Anatomy was unreliable. The positive sentiments were that Primal Pictures and Visible Body had useful features. Students did not comment positively on the learning support offered in Complete Anatomy, and faculty did not comment on any of the apps.

One student found that the quizzes within the platforms were not helpful as they were not USMLE-styled questions, but two others found that the quizzes helped reinforce their knowledge. In terms of learning content, one student shared that Visible Body had more complete content than the other two learning platforms.

In general, it was difficult to make a one-to-one comparison of similar features across the three digital anatomy platforms. For example, one student shared that Complete Anatomy allowed for customized 3D views to be saved that would otherwise be difficult to visualize in textbooks, while another student shared that Visible Body has better details in microanatomy and several students acknowledged that there was more content on Primal Pictures as compared with Complete Anatomy and Visible Body (see Table 6).

Faculty and student ranking. Respondents were asked to rank their preference of the three platforms that were evaluated. All six faculty members rated Primal Pictures as their top choice, while only 14% of students, or three students, rated it their top choice. 13 students (62%) rated Primal Pictures as their last choice. The reverse was also true in that the same number of students, 13 students, rated Complete Anatomy as their top choice, while 4 faculty (67%) rated Complete Anatomy as their last choice. Visible Body was ranked in the middle by most faculty members (67%), $n = 4$ and students (57%), $n = 12$. Table 7 summarizes faculty and students' ranking preference of the three platforms.

All faculty rated Primal Pictures as their first choice. All the faculty generally agreed that Primal Pictures provided the best balance between being user-friendly and meeting their teaching needs. One faculty shared that Primal Pictures has the best mix of details in the "Atlas feature" (3D Real Time) and has the best cross-sectional images mapped to actual CT scans and cadaveric images. However, the faculty also shared that the visual quality of the models of Visible Body and Complete Anatomy are higher than Primal Pictures, with Primal Pictures' 3D Atlas app looking less organized than Visible Body's Anatomy and Physiology app.

The positive feedback extracted from students' responses were that Primal Pictures had useful features, was detailed,

Table 6. Faculty and students feedback on learning support of the platforms.

	Primal Pictures		Visible Body		Complete Anatomy	
	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)	Faculty $N = 6$ mean (±SD)	Students $N = 21$ mean (±SD)
Usefulness, quality and range of lectures, 3D animations and/or Courses on anatomy-specific topics? (3D animations)	65 (18)	65 (24)	57 (15)	67 (22)	53 (24)	61 (26)
Ability to capture and share anatomical models using the tools provided?	73 (20)	62 (27)	60 (20)	61 (26)	48 (29)	50 (29)
Usefulness of feature to create quizzes and share them with students?	65 (19)	NA	58 (20)	NA	47 (23)	NA
Ease of use, functionality and completeness of mobile App version?	62 (19)	50 (26)	52 (13)	74 (18)	52 (25)	76 (21)

Response options on a 100 point scale with 0 = strongly disagree to 100 strongly agree. Average scores are expressed in means (±SD).

Table 7. Ranking preference of digital human anatomy platform.

	Primal Pictures		Visible Body		Complete Anatomy	
Ranking preference	Faculty % (*n*)	Student % (*n*)	Faculty % (*n*)	Student % (*n*)	Faculty % (*n*)	Student % (*n*)
1st	100 (6)	14 (3)	0	24 (5)	0	62 (13)
2nd	0	24 (5)	67 (4)	57 (12)	33 (2)	19 (4)
3rd	0	62 (13)	33 (2)	19 (4)	67 (4)	19 (4)

and accurate; Complete Anatomy had great usability, was detailed, had helpful features, and a good level of amenability; and Visible Body was balanced, had good usability, as well as useful features. The negative feedback from students was that Primal Pictures had poor usability, amenability, and a lack of features; some students noted that both Complete Anatomy and Visible Body had poor usability, as well as a lack of detail. Qualitative comments among faculty were slightly different, where faculty positively noted that Primal Pictures had the highest level of detail, had the best balance, useful features, a good level of amenability, and was suited for the curriculum in the institution. Complete Anatomy was noted to have good visual quality, and Visible Body was noted to have an organized interface. Negative sentiments from faculty noted that despite Primal Pictures having many positive qualities, it was low in visual quality; and Complete Anatomy and Visible Body had a lack of features.

Below are sample responses for overall comments from 2 faculty members:

> "From what I see so far, Primal Pictures has the best mix of detail in annotations in the atlas feature (which they call their 3D real time app), and has the best cross-sectional images mapped to actual CT scans as well as cadaveric images." (Faculty 1)

> "Overall, I feel primal pictures has the most balance between being user friendly and being accurate." (Faculty 3)

The pedagogical value of Primal Pictures to faculty was also highlighted with respect to the curriculum, as well as the flexibility afforded to the faculty, with the respondents stating:

> "Primal Pictures was the most suitable for the needs of curriculum design and management." (Faculty 5)

> "Primal Pictures is the most versatile in allowing faculty to create their own teaching material." (Faculty 6)

On the other hand, 62% ($n = 13$) of students rated Complete Anatomy as their first choice, compared to none of the faculty. The two most prevalent reasons behind the high ratings for Complete Anatomy related to the application's ease of use and straightforwardness when navigating the human anatomy. One student shared that the purpose for using these human anatomy platforms was to supplement in-class sessions, and it would be essential to have a tool that is easy for him to "make the connections between the various organ systems and layers together." Similarly, another student shared that the clean interface and ability to share "saved views" in Complete Anatomy allows tutors to share content with students easily. While students acknowledged that Primal Pictures has accurate and more detailed information on various anatomical regions, several students cited difficulty in navigation and software lag as their primary challenges when using Primal Pictures.

The overall rankings suggest a difference in the preference for digital anatomy platforms between faculty members and students. Faculty members have a stronger preference for using Primal Pictures in anatomy teaching, while students have a stronger preference for using Complete Anatomy in anatomy learning. The survey showed that faculty members sometimes had diverging satisfaction ratings, while students generally had a positive satisfaction rating across all three digital human anatomy platforms. While the survey showed that faculty members and students were satisfied with all three platforms evaluated, the qualitative feedback provided more insights into their ratings.

Discussion

The results indicate a difference in what students and faculty deem important when selecting a digital learning resource. Most students rated Complete Anatomy as their top choice, and the overwhelming corresponding reason, as noted from the analysis of their qualitative answers, was that the application was easy to use. On the other hand, the most popular application among faculty was Primal Pictures, with the quality and usefulness of its features and high level of detail garnering much favor. Unlike students, none of the faculty members commented on navigation or ease of use in their feedback.

Navigation and ease of use of the learning platforms seem key for students, with several commenting students on this, but not the faculty. Students' prioritization of ease of use is evidenced in their preference for platforms that can quickly become intuitive to use. One explanation for the findings is that students are newer to the subject matter than faculty members and prefer a platform that makes their learning experience of the unfamiliar content easier. It must be acknowledged that a prominent criticism by both faculty and students towards Complete Anatomy is related to its lack of detail or depth. However, though both students and faculty voiced out this criticism, only students did not let it affect their ratings for their preferred platform. Our findings were consistent with a study by Zilverschoon et al[35] suggesting that medical students who are trying to master basic structures of the human anatomy have less need for highly realistic models, but specialists and faculty, on the other hand, would require more realistic and detailed models given their familiarity with the content which allows them to be more critical toward inaccuracies. Therefore, the difference in faculty and student preferences could be explained by their different levels of expertise in the subject.

In this study, students evaluated the platforms without specific instructions or learning activities from faculty members. From the student's perspective, these platforms are mainly used to supplement learning rather than as the primary information source. Some students shared that they used the platforms to supplement their learning through three-dimensional visualization of anatomy, with the depth of content not of primary concern when evaluating the platforms. They acknowledged that, while Primal Pictures had a better level of detail, their learning was hampered by difficulties in its usability and would require additional training to benefit from all its features fully. They also felt that if the platform had sufficient and accurate content for their learning purposes, usability (eg, ease of navigation, user interface) was more important than having more detailed or richer content (eg, cadaveric images). The technology acceptance model[51] posits that the "perceived ease of use" and "perceived usefulness of technology" influence a person's attitude towards that technology. Therefore, this could explain why there was a stronger preference for Complete Anatomy among students who perceive the system as more user-friendly, fostering a positive perception of its value and utility.[52,53]

Furthermore, literature has found that students frequently look to subjective and inaccurate indicators to measure learning effectiveness; namely, learning experiences that minimize effort and "feel" easy or fluent are misinterpreted as beneficial for learning,[37] and learning strategies that require high mental effort are perceived as less effective.[38] Students' JOLs based on the subjective sense of fluency during learning are often weakly or negatively correlated with actual improvement or performance.[36] A Roediger[54] study found that students' judgments on how well they performed a learning task were not always correlated with actual performance—students who adopted a learning strategy that felt easy but was less effective in reality (rereading a text) incorrectly believed that they performed better than students who adopted a strategy that was cognitively demanding, but more effective (self-testing). The ease of learning from a less demanding strategy resulted in a confidence boost that faltered the students' judgment. Indeed, as novices, students may lack the knowledge to evaluate learning resources or strategies to fulfill their learning needs.

This may help explain why students preferred Complete Anatomy more when evaluating the three digital anatomy platforms. Complete Anatomy was consistently rated higher for usability (Table 3) and interactive features (Table 4) despite students acknowledging that all three platforms provided a high level of detail of anatomical structures (Table 5). This inclination could stem from a perceived ease of use,[55] leading to a potentially skewed judgment regarding its effectiveness for their learning. It raises the question of whether students' preferences are guided more by the user experience than by the educational content's depth or accuracy. Such insights suggest that when students evaluate digital learning tools, their judgment of learning may be affected by the usability and interactivity in their perceived learning efficacy, possibly overshadowing other critical educational value factors. This observation calls for a deeper investigation into how digital learning platforms can balance intricate details and educational rigor with intuitive design and engaging features to help students learn.

In terms of subject matter and pedagogy, faculty members are knowledge experts and have a better understanding of how the chosen technological teaching material will be applied clinically and to the curriculum. Being experts, they integrate and organize their knowledge more efficiently than novices,[56] and have different motivations and strategies for accessing their knowledge.[57] Hence, this can give rise to differences in judgment of the effectiveness of a learning resource. The feedback showed that students tended to evaluate the apps by focusing on the features of the apps that made their learning experience more pleasant, such as ease of use and navigation, whereas almost none of the faculty members focalized the features that affected user experience in their review of the apps. This corroborates extant literature on how students' judgment might gear towards being more subjective,[36,37]

focusing on different features to judge the effectiveness of a particular application as compared to experts.

Another observation was that students rated all three digital anatomy platforms high in the level of detail, while faculty rated Primal Pictures as a better platform than Complete Anatomy. With their limited exposure and expertise, students may have a more positive overall perception of all platforms, being drawn to novel, engaging, or user-friendly features.[58] In contrast, faculty members, drawing upon their extensive experience and critical eye, may have evaluated Primal Pictures more favorably due to a deeper understanding of the platforms' nuances and limitations. This discrepancy could stem from students' relatively limited experience and familiarity with such platforms, which might lead them to form a more favorable impression across the board, particularly swayed by the novelty, engagement factor, or ease of use these platforms provide. It is possible that students feel they have gained insights from each platform,[38] yet their comparative evaluation skills may not be as refined, hindering their ability to discern which platform is superior.

These results have implications for learning resource selection and the value of student and faculty feedback. If anatomy teaching is to be transitioned online or take on a more blended approach, it is important to incorporate technology with a curriculum design framework that is pedagogically sound and supported by an understanding of what makes the learning work for students.[59] As educators, we should simultaneously consider students' feedback in learning and ensure that our approach is pedagogically sound, as what students want may not always be in their best interest for learning. The three-dimensional nature of learning anatomy is traditionally experiential[60] and requires educators to consider how the tools for teaching can create a supportive learning environment. Giving students the tools without scaffolding with learning activities[61] may not necessarily mean that students will use the tools effectively or how the faculty member would have intended.

Students have diverse needs and preferences when learning. The user-friendly features and ease of use of digital learning platforms may have an effect on their intention to use and judgment of learning despite the difference in the quality and level of details of these learning platforms. A well-designed platform that aligns with the student's needs and expectations can foster an environment that can engage them in deeper learning. When a student finds the learning process seamless, they are more likely to be engaged in the learning process,[59,62] in turn, reinforces their learning and potentially leads to better academic performance. Future researchers may like to consider the relationship between a student's learning preference for a certain learning platform and their learning outcomes.

We do not believe that digital human anatomy platforms will completely replace cadaveric dissections anytime soon, despite some schools considering not using cadaveric material in their teaching.[32,47] However, with the increasing difficulty in obtaining cadavers for anatomy teaching, these platforms can further augment and supplement learning for students. It is important to incorporate deliberate, active learning strategies that would engage learners in and out of the classroom. Technology is only an enabler and cannot replace the role faculty members play in teaching, but it can serve to motivate students to study a complex anatomical structure.[48,63] Therefore, faculty members must create learning opportunities that would motivate students to leverage technology in learning.

Limitations

Our studies had several limitations. The survey of only 6 faculty members and 21 students in the MD Program posed challenges in establishing meaningful statistical significance. The survey's primary objective was to gather feedback from key faculty and students, aiding the authors' institution in making informed decisions about subscribing to a digital anatomy platform with no internal validity conducted on the survey items. Another limitation is the extent to which faculty members and students provided qualitative feedback in the open-ended questions. Students demonstrated more willingness to share their insights, while responses from faculty were limited. It is further noted that 15 students (60%) regularly used Complete Anatomy before the survey and were familiar with the platform (See Table 2), and students acknowledged this as a potential source of bias when ranking their choice of anatomy learning platforms. Students who provided feedback were at different stages in their medical school journey, which may affect their preference and satisfaction when evaluating the three digital human anatomy platforms. Another limitation of the study is that no formal learning activities were designed for students to explore using the different platforms, which may have affected the study outcomes.

Conclusion

The findings suggest a difference in learning platform preference between faculty members and students. However, faculty members and students were generally satisfied with all three digital human anatomy platforms. While some platforms may have additional features, each has its unique affordances that may serve a different purpose. We suggest that when evaluating and selecting a digital human anatomy platform, an explicit pedagogy and strategy on how the technology will be incorporated into the curriculum should be identified so that the specific affordances in the learning platform can be maximized.

Ethics statement

This study received Exempt Approval from the Learning and Analytics Committee on Ethics, National University of Singapore (Approval Ref: L2020-12-01).

Supplemental Material

Supplemental material for this article is available online.

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