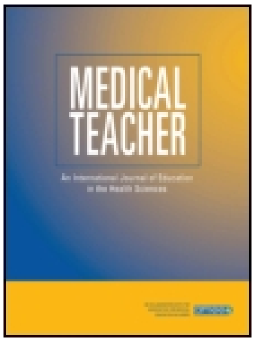
Taylor & Francis
Taylor & Francis Group



Medical Teacher

ISSN: 0142-159X (Print) 1466-187X (Online) Journal homepage: http://www.tandfonline.com/loi/imte20

Design principles for developing an efficient clinical anatomy course

Lawrence J. Rizzolo, William B. Stewart, Michael O'Brien, Andrew Haims, William Rando, James Abrahams, Shane Dunne, Silas Wang & Marcus Aden

To cite this article: Lawrence J. Rizzolo, William B. Stewart, Michael O'Brien, Andrew Haims, William Rando, James Abrahams, Shane Dunne, Silas Wang & Marcus Aden (2006) Design principles for developing an efficient clinical anatomy course, Medical Teacher, 28:2, 142-151, DOI: 10.1080/01421590500343065

To link to this article: http://dx.doi.org/10.1080/01421590500343065

Medical Teacher, Vol. 28, No. 2, 2006, pp. 142–151

Taylor & Francis
Taylor & Francis Group

Design principles for developing an efficient clinical anatomy course

LAWRENCE J. RIZZOLO[1], WILLIAM B. STEWART[1], MICHAEL O'BRIEN[1], ANDREW HAIMS[2], WILLIAM RANDO[3], JAMES ABRAHAMS[2], SHANE DUNNE[4], SILAS WANG[1] & MARCUS ADEN[1]

[1]Department of Surgery, Yale University School of Medicine, USA; [2]Department of Radiology, Yale University School of Medicine, USA; [3]McDougal Graduate Teaching Center, Yale University School of Medicine, USA; [4]Ophthalmic Technologies, Inc., Toronto, Canada

ABSTRACT *The exponential growth of medical knowledge presents a challenge for the medical school curriculum. Because anatomy is traditionally a long course, it is an attractive target to reduce course hours, yet designing courses that produce students with less understanding of human anatomy is not a viable option. Faced with the challenge of teaching more anatomy with less time, we set out to understand how students employ instructional media to learn anatomy inside and outside of the classroom. We developed a series of pilot programs to explore how students learn anatomy and, in particular, how they combine instructional technology with more traditional classroom and laboratory-based learning. We then integrated what we learned with principles of effective instruction to design a course that makes the most efficient use of students' in-class and out-of-class learning. Overall, we concluded that our new anatomy course needed to focus on transforming how medical students think, reason, and learn. We are currently testing the hypothesis that this novel approach will enhance the ability of students to recall and expand their base of anatomical knowledge throughout their medical school training and beyond.*

Practice points

- Common clinical cases can guide the selection of content for a shortened first-year anatomy course that suitably prepares students for the rest of their medical training.
- The anatomy course should be organized around problem-solving exercises with extensive formative assessment.
- Students profit most when multiple, problem-oriented modalities are integrated, including dissection, computer exercises, radiology and small group discussion.
- The success of an introductory anatomy course should be measured after a year or more when students enter the clerkships. This will determine how well fundamental concepts can be recalled, and whether students were able to expand their understanding by linking anatomy to subsequent course material.

Introduction

Clinical education presents a daunting challenge. With the extraordinary progress of biomedical science, physicians must be trained in an increasing array of technical disciplines, placing pressure on traditional courses, like anatomy, to re-evaluate what students need to learn, and to identify the most efficient ways to teach. In fact, the trend towards shorter anatomy courses has begun (Drake *et al.*, 2002; Heylings, 2002).

Current pressure to reduce the hours devoted to anatomy education notwithstanding, research suggests that traditional anatomy courses inadequately prepare new graduates for their residency training (Collins *et al.*, 1994; Gordinier *et al.*, 1995; Ger, 1996; Cottam, 1999; DiCaprio *et al.*, 2003). One reason for this condition is the pedagogical principle upon which traditional anatomy education is built, that being comprehensive coverage. While reasonable on its face, numerous studies and a plethora of anecdotal evidence suggest that simply covering the material fails to produce lasting understanding. What's more, the way medical students learn anatomy with the 'coverage model' does not meet the demands of clinical practice. Clinicians today: (a) understand the human body from a practical, disease-based perspective; (b) use complex digital media to diagnose illness; and (c) need to enhance their understanding of anatomy throughout their careers. Clearly, with traditional methods in dispute and hours devoted to anatomy education declining, the need for more effective pedagogy is greater than ever before.

We set out to design a new, more efficient anatomy course, by assembling a diverse design team made up of specialists in anatomy, clinical medicine, instructional technology, pedagogy and instructional assessment. We began by examining how our students use computers to learn anatomy. Studies show that web-based computer exercises have become a popular means to supplement and enhance traditional dissection (Kim *et al.*, 2003). One of our earlier studies indicates students' preference for interactive exercises that require problem-solving and provide immediate feedback (Rizzolo *et al.*, 2002).

We then turned to the literature on effective pedagogy for guidance as to how a course might exploit students' predilections while meeting the curricular demands of

---

Correspondence: Lawrence J. Rizzolo, Department of Surgery, Yale University School of Medicine, PO Box 208062, New Haven, CT 06520-8062, USA. Tel: 203 785-6277; fax: 203 737-2825; email: Lawrence.Rizzolo@yale.edu

ISSN 0142–159X print/ISSN 1466–187X online/06/020142–10 © 2006 Taylor & Francis
DOI: 10.1080/01421590500343065

modern medical education. Studies indicate that if material is learned in the context in which it will be used, retention and understanding are enhanced (Arseneau & Rodenburg, 1998; Mann, 2002), findings which provide an explanation for the unsatisfying results of traditional, acontextual anatomy education. The literature on professional education (Mezirow, 1990; Brookfield, 1991; Argyris & Schon, 1992), establishes the importance of context, problem-solving, autonomous instruction, and feedback as important instructional design principles. One element of context that seemed particularly important for medical education is the ubiquitous experience of small-group, interactive problem-solving. It is the dominant modality of both clinical practice and clinical research. In sum, our initial exploration provided a blueprint for a pilot anatomy course focusing on reasoning, learning, and transformation rather than simple coverage and memory, and generating data and insights for a totally redesigned course in anatomy.

In this paper, we present a description of that pilot study. We begin by describing our team's development of *instructional materials* that complement traditional dissection exercises for the laboratory, conference, computer and web. We then present the *assessment tools* we designed to collect data from our pilot study, including surveys of students experiences with the experimental instructional materials, tests of performance in key conceptual areas, and focus-group studies on changes in students' learning behavior, as well as any unanticipated consequences of our intervention. After we present the *results* of these assessments, we describe how we transformed our experience with the pilot study to develop a set of *design principles* for a more clinically grounded anatomy laboratory course.

Materials

In the three years leading up to our fully redesigned course, we identified (and in some cases developed) a range of instructional technologies and ran a series of pilot studies to gather data on how students use them and how they affected learning. The technologies include: (a) light-box exercises for training in radiology; (b) holograms derived from computed tomography; (c) highly-interactive web-based activities; and (d) a novel computer program to manipulate Visible Human images.

Radiology: light boxes

Light box exercises applied to the lessons from corresponding lectures given by faculty from the Department of Diagnostic Radiology. The instructions were organized in program-text (question–answer) format to guide students through their examination of plain film, computed tomography (CT) and magnetic resonance imaging (MRI) studies.

Holograms

Holograms derived from CTs and MRIs were produced by Holovad (Salt Lake City, UT). The holograms were offered as supplementary material. Program-text exercises were created to guide students through the hologram. Holograms made from CTs and MRIs are accurate, semi-translucent, three-dimensional representations of the anatomy that are suspended in space. Students can insert their fingers in the hologram to trace structures and see three-dimensional relationships that can be distorted by dissection. Holograms potentially serve two functions. First, they can be a stepping stone to understanding radiographic images by illustrating how overlapping structures contribute to the appearance of the plain film. By 'slicing' the hologram, it is easy to see how MRI or CT slices can be reassembled to form a three-dimensional structure. Second, they can help students visualize complex structures, such as the vascular system of the brain.

Web activities

Web activities and quizzes were developed using the standard utilities of Blackboard (Blackboard, Inc., www.blackboard.com), Macromedia Flash MX (Macromedia, Inc., www.macromedia.com) and First-Page 2000 web design software (www.eversoft.com). Our earlier studies revealed that students favor the web for self-assessment much more than for content (Rizzolo *et al*., 2002). We exploited this behavior by designing highly-interactive web activities to model experimentation and spatial reasoning. Three levels of activity were designed. The entry-level activities involved simple point and click exercises to learn the names of key structures and their appearance in various views and planes of section. Intermediate level activities were designed to guide students through a thought process that could be applied in the dissection and radiology laboratories. These exercises involved decision trees, where the question posed depended upon the previous answer. An incorrect response was followed by a series of questions designed to help the student learn about their choice. Then students were returned to the original question to try again with the benefit of their newly acquired knowledge.

An example of an advanced level activity is the analysis of gait. This activity was developed in collaboration with the Section of Geriatrics, where gait is routinely analyzed. As only a subset of a large number of nerves and muscles is required for this analysis, the exercise focuses attention on clinically relevant anatomy. The activity asks students to diagnose a man who presents with foot-drop. After viewing a video clip of the man walking, the web activity allows students to choose which muscle tests they wish to perform, watch a video of the clinician performing the test, and make a judgment about the result. When students make mistakes, the program provides feedback based on their choice and directs them towards the relevant muscle exam.

The Divisible Human

To cultivate spatial reasoning, we used a computer program 'The Divisible Human'. The Divisible Human software was developed by S. Dunne (Ophthalmic Technologies, Inc., Toronto, Canada). The program mimics the presentation of CT and MRI data that are now becoming standard in clinical practice. Divisible Human allows the user to select a region of the body, choose any plane of section and, using a slider in real time, view serial, sectional images through the Visible Human (http://www.nlm.nih.gov/research/visible) in the

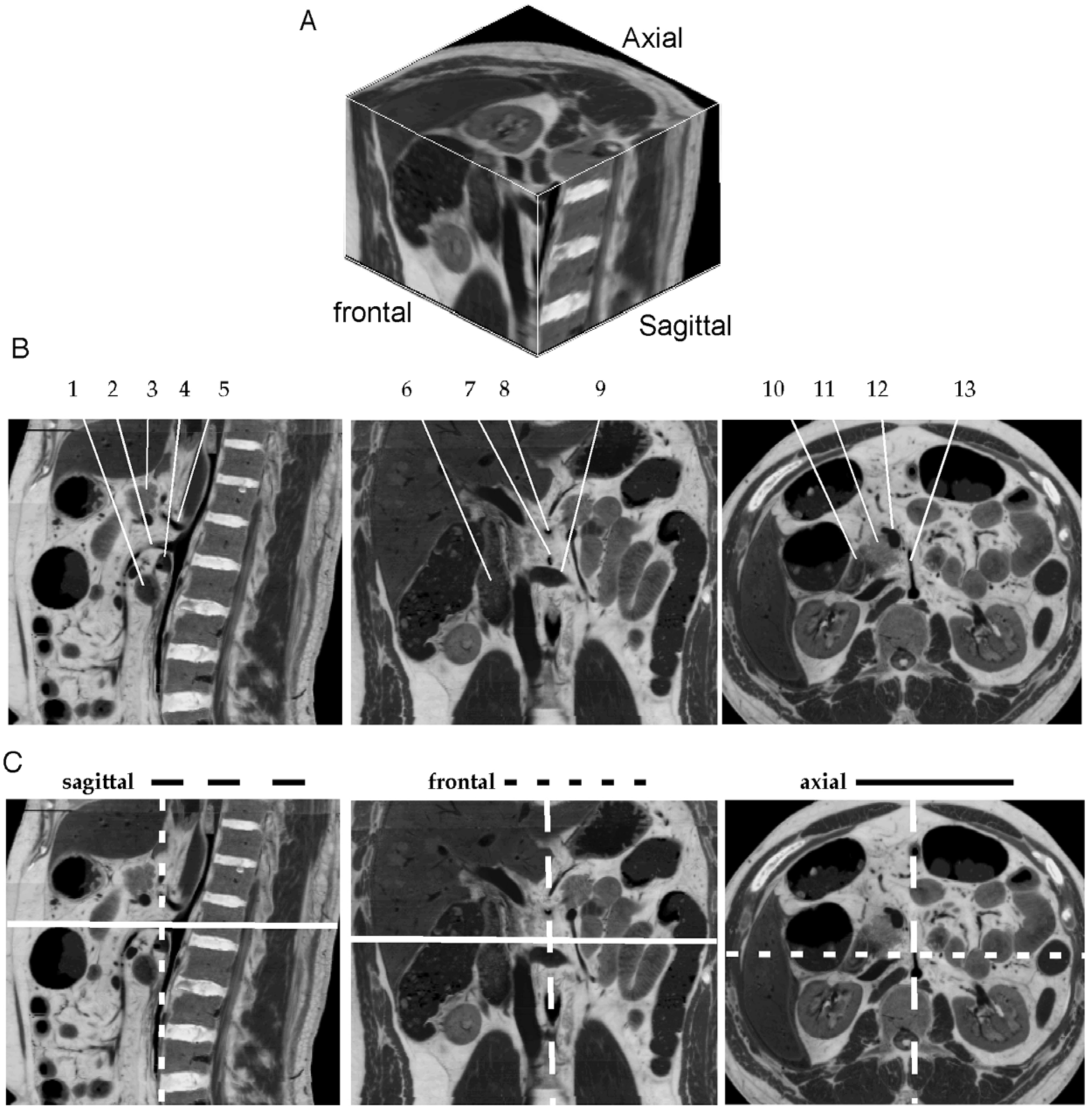


Figure 1. Orthogonal Divisible Human images that highlight relationships in the upper abdomen. (A) A block that was trimmed electronically to simultaneous reveal sagittal, coronal and axial planes that intersect at the origin of the superior mesenteric artery. (B) The planes in (A) were expanded to full size. The sagittal image (left) emphasizes the relationships among the duodenum (1), superior mesenteric artery (2), and left renal vein (4) as well as the relationship between the pancreas (3) and celiac artery (5). The coronal image (center) reveals the relationship between the renal vein and the superior mesenteric artery (7 and 9), as well as the proximity of the celiac trunk (8). In addition, the descending part of the duodenum (6) is visible. The axial plane (right) emphasizes the close spatial relationships of the duodenum, pancreas, portal vein and superior mesenteric artery (10, 11, 12, and 13). C) Panel (B) is repeated with lines that indicate where each plane intersects the other. The label indicates the plane of section and the label's line corresponds to the lines of intersection.

selected plane. By using triangulation, students can use one plane of section to help identify structures in a second plane. Figure 1A shows a block taken from the abdomen and trimmed or sectioned electronically along the axial, coronal and sagittal block-faces. The block was tilted to simultaneously exhibit all three faces. Because no structures are labeled, students use logic and experimentation to prove identifications. In Figure 1A, the corner of the block that points towards the viewer is in the superior mesenteric artery. To examine the relation of the artery to its neighbors, the student can expand each block-face (plane) in turn, as shown in Figure 1B. In this way, and by using sliders to move the block-faces in one direction or the other, students explore the connectivity and nearest-neighbor relations of structures to arrive at an identification. Next, they determine if their logic convinces a colleague or instructor. The goals are to stimulate debate, give students practice articulating anatomical knowledge and experience applying that knowledge to solve a problem using group process.

Assessment methods

Radiology: light boxes

To assess students' perceptions of their Radiology experience, we administered a survey, at the end of the course, and asked for comments.

Table 1. Summary of student responses to hologram activities.

	Total responses	% Total respondents
Positive comments	32	41
Solidified 3D relationships	12	15
Would like more activities	6	8
Helped visualize vascular system	4	5
Instructors enhanced the activity	6	8
Negative comments	8	10
I see how it might help others	4	5
Hard to see the image	6	8
No comment	38	49

Notes: An end-of-the-year course evaluation asked students to comment on the web activities. The responses were coded and grouped into the themes of positive and negative. The most common reasons are listed with the number of students citing those reasons and the percentage of the 78 students who participated the survey.

Holograms

The perceived efficacy of holograms and web activities (see below) was assessed in students' course evaluations. Students were asked to rate the effectiveness of the holograms using a 5-point Likert scale (1 = ineffective; 5 = very effective). The evaluations also asked students to submit open-ended written comments on these resources. Student responses were coded, as indicated in Tables 1 and 3. The codes and tabulation were confirmed by two independent investigators.

Web activities

To test the efficacy of the web activities, we included questions related to them in the final exam. We then correlated students' performance on these questions with the number of times they logged on to the relevant activity. The average score of students who logged on one or no times was compared to that of students who logged on three or more times. A student who logged on only once may not have actually used the activity, but we assumed that students who returned three or more times incorporated the activity into their study plan. We made the same comparison for only those students who scored below the mean and again for only those who scored above the mean of the entire test. Dividing the class in this way insured that there were at least 15 students in each category. Tests of significance were made using Student's t-test.

The divisible human

To assess students' spatial reasoning abilities, we asked students to solve problems such as presented in Figure 1B, where labeled structures were to be matched with names from a list. A strategy for analyzing this problem is to use careful observation to determine where these planes intersect (Figure 1C). This knowledge allows information from two images to be combined. For example, sagittal views near the midline are ubiquitous and easily understood.

The results were analyzed by comparing the performance of the students whose total exam score was in the top 20% ($n = 20$ students) with that of students whose score was in the bottom 20% ($n = 20$ students).

Focus groups

Following the Action Science research methodology described by Argyris & Schon (1992) our learning intervention included opportunities for students to participate in the development and critique of the new system. All students were invited to participate in two, hour-and-a-half development sessions. Thirty students chose to participate. We had a two-fold goal for each discussion session: (1) to give students a chance to reflect on how they study and learn anatomy; and (2) in doing so, to gain a better understanding of how best to organize the new course.

Results

In this section we provide quantitative results accompanied by representative qualitative results in the form of quotations from students' comments. These quotations are not presented as empirical proof, but rather as examples of typical language structures students used to express their attitudes and perceptions. We believe that these statements, taken together, illustrate not only students' attitudes but also the motivations and contexts in which these attitudes are formed.

Radiology: light boxes

We collected data on students' perceptions of our radiology intervention by asking them to complete an end-of-course survey. Of 78 respondents (100 students total), 22 (~30%) volunteered comments about radiology. Eighty percent of these were very favorable. A typical comment was:

> 'I really like the heavy focus on radiology; it helps bring everything together, and ensures us that we're learning an important tool that we'll use for a long time'.

Some suggestions were offered, mostly for more films of normal patients, models and holograms. The negative commentators asked mainly for more instructors and more time to complete the exercises. The following comment summarizes these views:

> 'Radiology labs would be more effective with: radiographs showing "normal" views for comparison, models, more radiologists/residents to help us understand problem/implications[of the] tests'.

Holograms

We used a Likert scale assessment to collect data on the hologram activities, which received an average score of 4.0 (1 = ineffective; 5 = very effective). Additionally, 38 (48% of respondents) students offered comments in a year-end survey

Table 2. Correlation of web activities on exam questions.

Topic	Total points	All students		Below average exam score		Above average exam score	
		Frequent	Infrequent	Frequent	Infrequent	Frequent	Infrequent
Gait	2	1.8	1.6	1.9	1.5†	1.9	1.7
Fetal blood flow	5	4.3	2.6*	3.9	2.3*	4.1	3.7
ASD[1] in the aged	5	4.0	2.8*	3.8	2.2†	4.2	2.4*
Bladder control	2	1.6	0.9*	1.5	0.6*	1.7	1.4
Nervous system	13	9.2	6.8*	6.4	5.5	11.2	8.4*

Notes: [1] ASD; atrial septal defect. The average score on questions related to web activities on the indicated topics were calculated. Frequent users (opened the web activity three or more times) were compared to infrequent users (opened the web activity once or not at all). Approximately one third of the class fell into each category. The class was further divided into those whose total score on the exam was above average or below average. *$p < 0.01$, †$p < 0.05$.

(Table 1). Thirty-two of these 38 were favorable and cited the utility of holograms in understanding the anatomy in three-dimensions, especially the vasculature, and helping understand radiology.

> 'The holograms were particularly helpful in visualizing blood supply, i.e. Circle of Willis'.

> 'I found the hologram exercises to be very useful in visualizing 3-D relationships that were otherwise hard to grasp'.

Six of the 32 favorable respondents requested more holograms.

Of the eight students who stated they did not like the holograms, four felt they could already 'see' the anatomy in three-dimensions and that traditional resources were sufficient.

> 'The holograms weren't helpful to me - but I had a good spatial orientation before it started. I could see how they were helpful for others'.

Six students thought the holograms were hard to see. It may be that the holograms do not work well as stand-alone exercises. For example, one student said:

> 'The holograms were terrific once you learn how to use them'.

> 'I liked the holograms, but could never see the image when instructed to "flip" the screen'.

This latter comment indicates that the written instructions for how to use the holograms were unclear for some students. Several students commented on formally incorporating holograms into the radiology lab.

> 'I think it would have been helpful to have all of the hologram exercises incorporated with the radiology [labs]. In this way, one can be assured that a faculty member is available for student questions'.

Web activities

Looking at students' use of web activities, user-log data indicated that while students studied quizzes and old exams primarily right before an exam, web activities were used in addition when the relevant topic was covered in the dissection lab. We also examined the relationship between students' use of web-activities and performance on the final exam (Table 2). We took a very conservative approach to determining which students made significant use of web activities and which students did not. Based upon user log data for each topic of web activity, we identified two groups of students: infrequent users (those who logged on 0–1 times), and frequent users (those who logged on three or more times). Approximately one third of the class (30 or more students) fell into each category. Looking at the exam questions that corresponded to each group of web activities (five in all) we compared the students' answers with their web activity usage. For four of the five web-activities, frequent users of the activity out-performed infrequent users. On the fifth (and easiest) question dealing with gait, the difference between the groups was statistically insignificant. We also took into account the possibility that frequent users may be those who study everything and would have done well anyway. To address this, frequent and infrequent users were further divided into those whose final grade was above or below average.

When the bottom half of the class was examined, frequent users still out-performed infrequent users for four of the five web-activities. Within this bottom group, the gait exercise appeared to benefit those who used it frequently. In other words, for easy topics the web activities were still helpful to the weaker students. When the top half of the class was examined, a statistical difference was observed for the more difficult questions about atrial septal defects (ASD), and about the organization of the nervous system. Both the top and bottom of the class appeared to benefit from the ASD exercises. By contrast, the nervous system questions proved to be the most difficult for the class as a whole, and only the top half of the class was able to benefit from the associated web activity. For the other activities, there were no statistical differences among the frequent users, regardless of their final exam score. In other words, those bottom students who frequented the web activities performed as well as top students. In summary, for some topics the web activities appeared to benefit the weaker students but were not required by the stronger students. For more challenging topics the stronger students also benefited.

Table 3. Summary of student responses to web activities.

	Total responses	% total respondents
Positive	52	66
Mixed	7	9
Negative	2	3
No comment	17	22
Positive comments		
best way to learn	11	14
would like more activities	21	27
because they integrate/focus	6	8
because they interactive/fun	10	13
Negative comments		
various computer problems	3	4
too easy	6	8
site organization	2	3

Notes: An end-of-the-year course evaluation asked students to comment on the web activities. The responses were coded and group into the themes of positive, mixed and negative. The most common reasons are listed with the number of students citing those reasons and the percentage of the 78 students who participated the survey.

Table 4. Summary of performance on Divisible Human and MRI exam questions.

Question	Top 20%	Bottom 20%
Figure 1–Divisible Human		
(9) Left renal vein	86	55
(10) Duodenum	86	62
(13) Superior mesenteric artery	97	62
(12) Portal vein	93	69
Figure 2–Chest MRI		
(2) Left atrium	82	64
(8) Left atrium	90	64
(9) Lung	86	57

Notes: Items from the exam questions illustrated in Figures 1 and 2 were selected if fewer than 80% of the class identified them correctly. These are also the items that are difficult to identify without combining information from two or more images. The performance of students whose final exam score was in the top 20% was compared to students whose score was in the bottom 20%. Data indicate the percentage of students answering correctly within each group.

Students rated most elements of the course in a range from 3.9–4.2 on a 5.0 Likert scale, but the web activities were rated 4.8. Sixty-one of the 78 respondents offered comments (Table 3). Aside from a few negative comments related to technical issues, most comments were very favorable. Eleven students said these were the best way to learn. Many of the students requested more activities. When a reason was expressed, students commented that the activities were fun, interactive, helped them integrate the material, and helped them focus their attention.

In our focus groups, we asked students to discuss how they used web activities. Some students stated the web activities were useful for self-assessment, but most said the activities were valued for other reasons. The activities helped focus their attention and establish priorities.

> 'In lab I never really had a sense of what was extraneous and what was important and I think the web exercises gave me that understanding'.
> 'You could go thru lots and lots of layers of precision and getting more and more detail of all the muscles that are in there. So what's the right amount of knowledge? And then seeing a web exercise that demonstrated the matching of structure and function and gave measure of how much I needed to understand'.

The activities also help students integrate the material and synthesize concepts.

> 'Used it to solidify and synthesize information gathered before hand'.

> 'I found them very helpful for integrating functions which were presented in isolation in the text, as well as filtering out detail which was not functionally relevant or to highlight subtitles whose importance only became clear in the functional setting'.

The Divisible Human

On final exam questions, virtually all students recognized the characteristic shape of the superior mesenteric artery and its relations to the celiac trunk above and the left renal vein and duodenum below. But we were interested in their ability to transfer this information to the other planes of section. The data in Table 4 indicates that the top students more readily transferred information than the bottom students. More than 80% of the class could identify the items in Figure 1 except for the four items listed in Table 4. For these items, combination of information from multiple images helped make an identification. For example, consider (9), the left renal vein in the coronal plane, which the bottom students often mistook for the duodenum. The sagittal image demonstrates that the superior mesenteric and celiac arteries lie directly above the renal vein and that they must appear as circular profiles in any coronal plane that includes the renal vein and/or duodenum. Further, the renal vein or a large amount of fat separates the duodenum from the superior mesenteric artery. Many bottom students failed to apply that knowledge to the coronal image. This suggests that students who performed in the bottom 20% of the class resorted to rote memorization of this often-reproduced sagittal image to score well, but were unable to apply that knowledge to interpret a less common image.

These data suggest that top performing students had a good three-dimensional, mental image of the anatomy or the ability to combine information from multiple images. However, these students may have simply spent so much more time with the Divisible Human program that they became very familiar with this individual cadaver. In that event, pattern matching may have been more important than reasoning. To test this idea, the same test included a similar question about an MRI that the students had never seen. The set of images in Figure 2 highlights important spatial relations

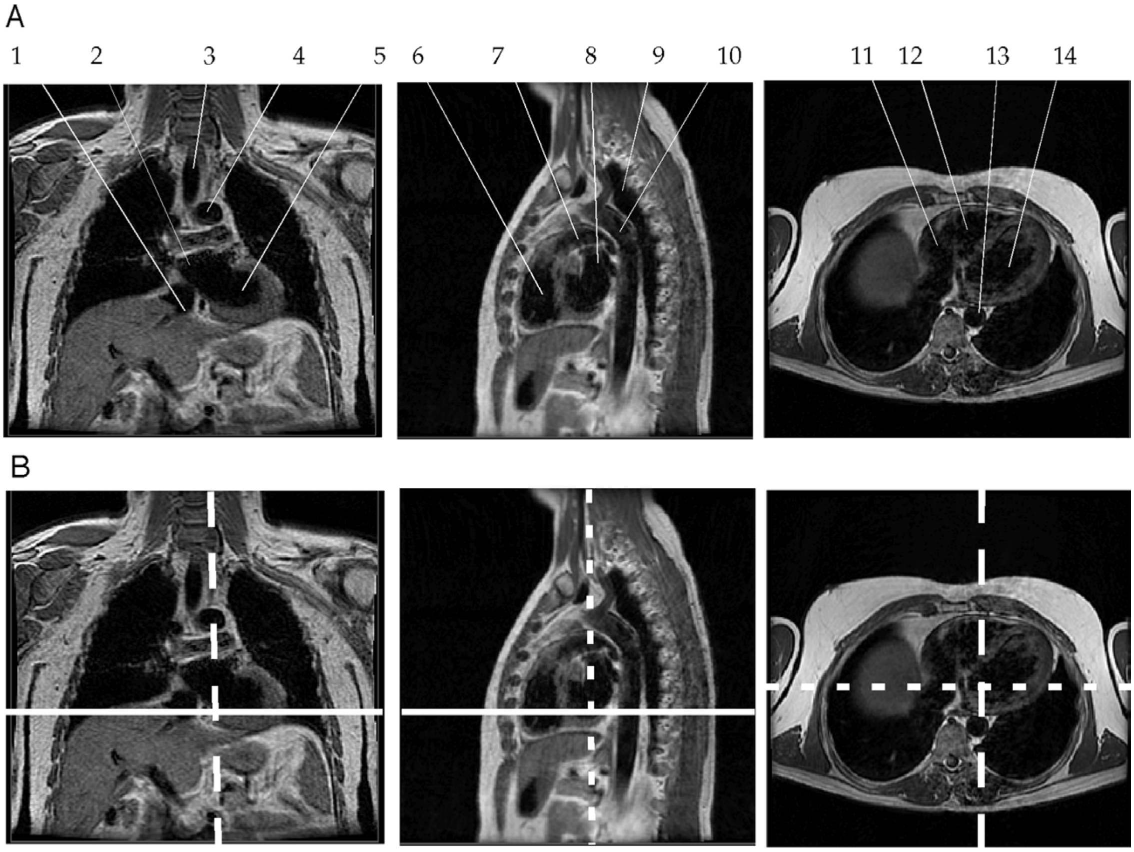


Figure 2. Orthogonal magnetic resonance images that highlight relationships in the chest. (A) The coronal image (left) emphasizes the relationships among the inferior vena cava (1), left atrium (2), trachea (3), arch of the aorta (4) and left ventricle (5). The sagittal image (center) reveals the relationships among the right ventricle (6), pulmonary artery (7), left atrium (8), lung (9) and aorta (10). The axial plane (right) emphasizes the relationships among the right atrium (11), right ventricle (12), descending aorta (13) and left ventricle (14). (B) Panel (A) is repeated with lines that indicate where each plane intersects the other.

of the heart, lungs and great vessels. Again, the only items that were difficult for the bottom performing students required three-dimensional reasoning (2, 8 and 9), but these items were not a problem for the top students (Table 4).

Because the program is separate from our web site, we had no way to link usage with exam performance. We were, however, able to use survey and focus group data to gain an understanding of students' preferences in using this type of tool. There was a nearly 50–50 split in student opinion about the Divisible Human. Those who did not like it almost always criticized the lack of labels and low number of instructors in the computer lab. To overcome this concern and help orient students, we created an atlas that identified a small set of landmarks. Although this dramatically reduced the need for instructors, half the class still preferred the myriad web sites and commercial products with labeled visible human images that can be studied alone. Did the students who liked Divisible Human use it to build a mental picture of anatomical relationships? Some valued the program this way:

> 'To better understand spatial relationship – this was key for my understanding'.

> 'I used this primarily before the final exam to test my understanding of where different body parts are in relation to each other. This really helped me with spatial understanding – particularly useful for understanding MRIs and CTs'.

Some thought it was a valuable learning tool that should have been introduced earlier in the course.

> 'I used the Divisible Human least of all – but I think it should have been emphasized earlier in the course. It was useful to grasp spatial relations'.

Some students did discover the program before it was formally introduced to the class and used it throughout the course.

> 'I loved this tool and I actually used it for learning and for fun throughout the course. As a tool for building a 3-D representation of the body in my mind'.

Discussion

Part I: what does all this research suggest?

The focus groups suggested that most students used the web activities alone, and not as a vehicle to promote discussion. Our radiology intervention, by contrast, found that groups of students would often discuss the radiology that was posted on the dissection laboratory light boxes, even outside of scheduled class hours. When asked how radiology differed from web activities, students noted that the answer keys to imaging studies did not explain why an answer is correct. The lack of an explanation promoted discussion, as students tried to figure it out. Because we value group process as a learning tool, this finding encourages us to strike a balance in the overall course design between activities that lend themselves to self-study and those that promote discussion.

The desire by some students for more time and faculty assistance speaks to the issue of transformational instruction. Although a small fraction of students could interpret radiographic images immediately, some students struggled the entire course to develop these skills. One student who spent many hours in extra-help sessions commented how she felt that MRIs of the brain were easier to interpret than those of the knee until she realized why. The hours spent on her initial exposure to MRI (of the knee) taught her skills that helped interpret any MRI. Despite the success of the radiology program, the requests for more instructors and time indicates that it is difficult for students to develop the spatial reasoning needed to understand radiology.

Looking at the hologram studies, the challenge for anatomy instruction is highlighted by the dichotomy between those who thought the holograms were superfluous and those who felt they were essential. The holograms helped by making radiology more accessible, especially to students with poor spatial skills. This allowed a greater portion of the class to appreciate the richness of the radiologist's instruction, and move on to address more sophisticated radiologic and anatomic concepts.

Encouraging as these results are, they do not address two important questions for a short course in clinical anatomy. There was a strong correlation between the use of interactive web-activities and exam performance, but top students may not have required all these web-activities (Table 2). Nonetheless, did the activities help top students master the concepts in less time? Learning theory states that recall is promoted by learning concepts in the context that they will be used. Will students more readily recall these concepts years later when they are in the clinic? Assessments described below are underway to investigate these issues.

The theme that runs throughout these comments is that Divisible Human promoted an understanding of relationships and three-dimensional imagery beyond what they learned in the dissection or radiology labs. None of the students who liked this resource claimed that it helped them learn or remember the names of things, nor that it focused their attention on specific topics, which may reflect differences in learning styles or a more fundamental difference in how well students understood and adopted the goals of the course. Our results suggest that the program favors students who like to learn through group process – an important clinical skill. In a subtle way, activities like this focus the students' attention by presenting problems that we consider important. They also reinforce nomenclature by stimulating the students to use it in discussion. The difficulty comes in persuading some students to take a risk by shifting time spent memorizing to time spent thinking three-dimensionally about anatomy and by discussing their ideas with colleagues.

Part II: design of a new course

As stated earlier, our goal is to redesign the anatomy course to make it more effective, less time consuming and more relevant to clinical practice.

Our observations, experiences, and research lead us to the following principles:

(1) *The anatomy should be presented in multiple formats*. Most students cited the diversity of approaches as a major strength. The following comment was typical:

> 'I believe dissection and clinical radiology labs and computer-based instruction contributed the most to the development of basic knowledge in anatomy. Dissection really helped me understand visually what was important; nothing beats the need to find the key structures and the ability to touch and feel them. Radiology labs help me visualize better what may be difficult to see or may be too messy in dissection lab. Computer-based instruction highlighted what was important and was easy to learn from, as most were interactive exercises'.

Anatomy becomes transformative rather than informative when students are challenged to learn through a combination of familiar and unfamiliar formats. To paraphrase one student, an effective learning mode is one that helps you understand the anatomy when it is considered in a different mode.

(2) *Common clinical cases should drive student inquiry*. The web activities that were effective at conveying complex concepts (Table 2) followed this principle. For example, rather than dissect the facial nerve in the cadaver lab and then discuss why its relations are important, students should prepare to perform a parotidectomy by investigating what structures will be placed at risk and the consequences of injuring them. The dissection becomes more meaningful, because the students learn the anatomy in the context in which they will use it. Medical and surgical cases concerned with common, fundamental problems can focus a short, introductory course on the anatomy that all clinicians should know. Because common cases will be revisited time and again in other coursework and in the clinic, common cases become a vehicle to review and expand anatomical knowledge and to link it to other medical disciplines.

(3) *The pedagogy should be problem oriented*. Consistent with our findings in the literature, the radiology, hologram and web activities demonstrate that students crave practice and formative self-assessments. Even though most of the web activities were un-graded, they provided immediate feedback that students could use to guide their future study. By extension, the dissection lab should be organized as a series of clinical problems that can be coordinated with radiology and web activities.

(4) *The course should promote group process*. Modern medicine is practiced in teams, and yet aside from exam preparation, most students have the habit of studying alone. Although dissection is a group effort,

it is easy for these experiences to slip into faculty-centered mini-lectures or demonstrations.

(5) *Self-assessment should be stressed over exam performance*. When students perceive high clinical relevance, a strong self-assessment program focuses attention on issues that are important, but difficult to test. The problems should be suitable for their level of training, and instructors must actively create a safe environment where students are unafraid to discuss their assessments openly.

(6) *Assessment of the course should continue into the clerkships*. To test the true effectiveness of the course, we need to test students when they enter clinical training – one and a half years after the anatomy course. This would provide a test of the hypothesis that learning-in-context promotes retention of material, the ability to link that material to future studies, and the ability to apply that material to clinical settings. Exams administered over the next two years will provide baseline data, before students from the new program reach the clerkships. The exam questions are based on topics identified by the clerkship faculty. Focus groups will explore student and faculty perceptions of student preparedness for the clerkships.

Part III: implimentation issues

Based upon the principles listed above, we set out to create the new course. To develop clinical cases, we consulted the clinical chairmen and section chiefs and sought input from the larger community at Grand Rounds. In all, 15 disciplines recommended over 100 cases and surgical procedures that cover all regions of the body, and that are common enough for a student to encounter similar cases during their clinical training. A working group of clinical faculty, residents and students helped identify broad learning objectives, which it used to choose the best and more relevant clinical cases. Physicians then contributed the history and physicals, surgical notes, imaging studies and discharge summaries for relevant patients. All patient identifiers were removed to protect patient privacy. Idealized cases were developed from this raw data.

Once the cases were developed, we refined our learning objectives and began developing the dissection and conference exercises to achieve them.

A good example of our development process is our decision that the course should begin in the same manner that a clinician begins with a patient – with the physical exam. We developed a lab that guides students over the anatomy of the body wall in a manner similar to a physical exam. This exercise will introduce students to the skeletal system and surface anatomy. We then decided that the next lab should build on the first by asking students to perform clinical procedures that invade the body wall, rather than the time-consuming process of skinning the entire body and teasing apart muscle layers. According to our principles, more relevant insights can be gained by comparing and contrasting the incisions that surgeons make at typical locations about the body wall. When incising the skin or inserting a chest tube, for example, students must investigate what nerves and vessels are placed at risk, the consequences of injuring them and how to avoid them. Although less time-consuming, this problem-solving approach should make the important concepts more compelling.

Next to the clinical case approach, the most innovative aspect the new course would be its reliance on formal small-group processes. Motivated by the instructional literature, and guided by principles of collaborative learning (Aronson *et al.*, 1978; Slavin, 1980; Johnson *et al.*, 1991; Kegan & Lahey, 2001), we organized students into five learning societies. A learning society is five dissection teams (four students per team) with a mentor that attend conferences, radiology workshops and dissection labs as a group. Creating a group identity and maximizing their time together in different activities should increase students' interactions with each other, enhance their ability to find and use relevant information, increase their capacity for self-direction and self-assessment, and decrease their dependence on the instructor. Recognizing that this mode of learning would be unfamiliar to many students, we determined that that the expectations and practices of team-learning be explained and supported throughout the semester.

To make up for the decrease in direct instruction by the faculty, students would prepare for the case-based labs under the guidance of a highly interactive, web-based dissector. The web-based dissector would guide their investigation of the anatomy that underlies the patient's presentation, physical exam, diagnostic imaging and surgical resolution. Students can link to web activities that lead them through the interpretation of plain films, contrast studies, MRIs and CTs. When they come to lab, the students will begin by discussing their preparations with their learning societies. Once all are satisfied that they understand the preparatory material, students will use the web-based dissector to guide them through the dissection. As a practical matter, only two members of a dissecting team can actually dissect at any given time, which means remaining members can research problems related to the dissection on the computer. By integrating the lab with supporting resources, instructors will be able to guide students in the use of each resource, and augment the feedback provided by computer exercises.

Throughout the duration of the course, students will provide assessment data in all the forms described above. While incredibly valuable in helping us understand the process of pedagogical transformation, no in-process data will allow us to assess the true effectiveness of our intervention. For this reason, we will continue to collect data from students and clerkship faculty for three years after students complete their anatomy course.

Conclusion

In summary, our qualitative and quantitative studies lead us to use common surgical and medical cases as the core of a revised anatomy course. Because small group discussion and problem-based exploration are commonly perceived as inefficient, it may seem contradictory to employ these methods to shorten a course. However, we find that this clinical approach focuses students' attention on the critical skills of spatial reasoning and the application of structure-function relationships, while freeing students from endless hours of memorization that produces little true learning. Further, we anticipate that students will be more able to link what they have learned to new concepts presented in subsequent courses and the clerkships. Consequently, they will more readily expand their understanding of clinical anatomy throughout their training and working lives. We believe we have designed a course that, rather than presenting details for memorization, should transform how a student thinks about anatomy and assimilates new knowledge. In short, we believe we have developed a course that gives students a strong foundation in anatomy, prepares them to assimilate a lifetime of new anatomical information, and does so in way that is more efficient and more educationally powerful than traditional anatomy education. We are designing assessment tools to test that hypothesis.

Notes on contributors

LAWRENCE RIZZOLO is Associate Professor in the Departments of Surgery and of Ophthalmology and Visual Science. He is the Director of Medical Studies for the Section of Anatomy and directs the course on Human Anatomy and Development. He received his PhD in Biochemistry from Duke University and postdoctoral training at Harvard University and NYU.

WILLIAM STEWART is Associate Professor in the Department of Surgery, where he is Chief of the Section of Anatomy. He received his PhD in Anatomy from Emory University and postdoctoral training at Yale University.

MICHAEL O'BRIEN is Adjunct Assistant Professor of Surgery. He received his MD and PhD degrees in Anatomy and Neuroscience from Bowman Gray School of Medicine and residency training in general surgery at Yale University.

ANDREW HAIMS is Assistant Professor of Radiology and Orthopedic Surgery. He received his MD from NYU School of Medicine. He did his residency in Diagnostic Radiology at Yale University and received additional training in Musculoskeletal Radiology at Thomas Jefferson University.

WILLIAM RANDO is Director of the McDougal Graduate Teaching Center at Yale University. He received his PhD in education and social policy from Northwestern University. Dr. Rando is co-author of *Learning from Students*.

JAMES ABRAHAMS is Professor of Diagnostic Radiology and Director of Medical Studies. He also directs the Neuroradiology Fellowship program. He received his MD degree from the Autonomus University of Guadalajara and did his radiology residency at Albany Medical Center. He did fellowships in neuroradiology at Albany Medical Center and Yale University.

SHANE DUNNE (who developed the Divisible Human software) is currently Vice President of Research and Development for Ophthalmic Technologies, Inc., a medical imaging device manufacturer based in Toronto, Canada. He received his PhD in Computer Science in 1995 from the University of Western Ontario.

SILAS WANG received his undergraduate degree in biomedical engineering from Harvard University and is a fifth year medical student.

MARCUS ADEN received his undergraduate degree in East Asian Studies from Harvard University. He has been programming HTML, JAVA script and Flash for 11 years.

Acknowledgements

The authors would like to thank the faculty of the Harvard-Macy Institute for their help in the design of this project and discussions of learning and assessment theory. We also thank Drs M. Drickamer and H. Chase (Yale University) for many helpful discussions. Supported by the Donald W. Reynolds Foundation and the Fund for the Improvement of Post-Secondary Education, US Department of Education (P116B031017).

References

ARGYRIS, C. & SCHÖN, D.A. (1992) *Theory in Practice: Increasing Professional Effectiveness* (San Francisco, Jossey-Bass Inc).

ARONSON, E., BRIDGEMAN, D. & GEFFNER, R. (1978) The effects of cooperative classroom structure on student behavior and attitudes, in: D. Bar Tal & L. Saxe (Eds) *Social Psychology of Education* (Washington, Hemisphere, DC).

ARSENEAU, R. & RODENBURG, D. (1998) The developmental perspective: cultivating ways of thinking, in: D.D. Pratt (Ed.) *Five Perspectives on Teaching in Adult and Higher Education* (Malabar, Kreiger, FL), pp. 105–149.

BROOKFIELD, S.D. (1991) *Understanding and Facilitating Adult Learning: A Comprehensive Analysis of Principles and Effective Practices* (San Francisco, CA, Jossey-Bass Inc.).

COLLINS, T.J., GIVEN, R.L., HULSEBOSCH, C.E. & MILLER, B.T. (1994) Status of gross anatomy in the US and Canada: Dilemma for the 21st Century, *Clinical Anatomy*, 7, pp. 275–296.

COTTAM, W.W. (1999) Adequacy of medical school gross anatomy education as perceived by certain postgraduate residency programs and anatomy course directors, *Clinical Anatomy*, 12, pp. 55–65.

DICAPRIO, M.R., COVEY, A. & BERNSTEIN, J. (2003) Curricular requirements for musculoskeletal medicine in American medical schools, *Journal of Bone and Joint Surgery (American)*, 85–A, pp. 565–567.

DRAKE, R.L., LOWRIE, D.J. Jr. & PREWITT, C.M. (2002) Survey of gross anatomy, microscopic anatomy, neuroscience, and embryology courses in medical school curricula in the United States, *Anatomical Record*, 269, pp. 118–122.

GER, R. (1996) Basic surgical training. 4: American and British scenes compared, *Clinical Anatomy*, 9, pp. 173–174.

GORDINIER, M.E., GRANAI, C.O., JACKSON, N.D. & METHENY, W.P. (1995) The effects of a course in cadaver dissection on resident knowledge of pelvic anatomy: an experimental study, *Obstetrics and Gynecology*, 86, pp. 137–139.

HEYLINGS, D.J. (2002) Anatomy 1999–2000: the curriculum, who teaches it and how?, *Medical Education*, 36, pp. 702–710.

JOHNSON, D.W., JOHNSON, R.T. & SMITH, K.A. (1991) Cooperative Learning: Increasing College Faculty Instructional Productivity, in: (Ed.) *ASHE-ERIC Higher Education Report No. 4* (Washington, DC).

KEGAN, R. & LAHEY, L.L. (2001) *How The Way We Talk Can Change The Way We Work: Seven Languages For Transformation* (San Francisco, CA, Jossey-Bass).

KIM, S., BRINKLEY, J.F. & ROSSE, C. (2003) Profile of on-line anatomy information resources: design and instructional implications, *Clinical Anatomy*, 16, pp. 55–71.

MANN, K.V. (2002) Thinking about learning: implications for principle-based professional education, *Journal of Continuing Education in the Health Professions*, 22, pp. 69–76.

MEZIROW, J. (1990) *Fostering Critical Reflection in Adulthood: A Guide to Transformative and Emancipatory Learning* (San Francisco, CA, Jossey-Bass Inc.).

RIZZOLO, L.J., ADEN, M. & STEWART, W.B. (2002) Correlation of Web usage and exam performance in a human anatomy and development course, *Clinical Anatomy*, 15, pp. 351–355.

SLAVIN, R.E. (1980) Cooperative learning in teams: State of the art, *Educational Psychologist*, 15, pp. 93–111.