A Brief History

Perhaps the best model in a modern anatomist’s teaching arsenal inarguably remains the cadaver [1]. The pedagogic symbiosis of student, facilitator, and cadaver is historically proven and hard to recreate. However, in the last quarter century, multiple iterations of anatomical education reforms [2–5], significant improvements in computing technology (price, ubiquity, software), and an increasing digital revolution in education has created a perfect storm for education. The classic Socratic and/or didactic approach has rapidly changed our “lecture” halls, classrooms, and labs to “shows” which now include visualizations such as diagrams, schematics, computer models, animations, videos, and even simulated environments [6]. Finally, in 2020, COVID-19 caused all formal education environments to pivot further towards digital learning environments. Anatomy departments around the globe that previously used cadaveric materials and small groups for their laboratory experiences now are dealing with government and institutional guidelines that supersede the peer to peer environments to which many of us are familiar [7]. These learning media form the basis of the more general term multimedia instruction, whereby both words and pictures are used to convey an instructional message [8].

Arguably, all anatomy instruction contains multimedia. Multimedia instruction occurs when educational messages are portrayed as a combination of spoken word and pictures [9]. Multimedia instruction should not be regarded solely as a high-tech phenomenon. Richard Mayer suggests that words can be spoken face-to-face or over speaker, speech can be computer generated, or words can exist as text. Pictures, on the other hand, are visual-spatial representations such as illustrations, drawings, schemata, or photographs delivered on a page or screen, while dynamic representations can exist as video or computer-generated animations that are delivered through a screen to an audience. In all cases, motivation for the use of images, and multimedia in general, is to promote learning. The impact of images (and multimedia in general) on learning may not be immediately evident, but over the course of multiple and ranging experiments, Mayer demonstrates that humans learn better from images and words than from the use of words alone. This is known as the multimedia principle [9].

As the reader will see later in this chapter, what and how we “do,” “say,” and “show” in our classes can have profound effects on learners.
through the multimedia principle. Furthermore, with an underlying social and technological current pushing for increasingly complex multimedia in our lectures, labs, and even assessments, educators may not achieve their objectives despite their best efforts.

**The Many Dimensions of Instructional Visualizations**

Multimedia instruction utilizing visually rich and interactive computer visualizations is a growing trend in anatomical education. From early computer images from A.D.A.M software (Atlanta, GA) to the newest incarnations of software designed to present human anatomy to a wide audience, the race to make the “best” software has significantly increased complex visualizations to all students and their educators [10, 11]. Regardless of the software manufacturer or approach the software might use, the images and text are the primary methods information is presented to the user; this is multimedia. Originally, the visualizations were termed virtual reality learning objects [12], and these digital anatomical “models” have become increasingly flexible and complex as researchers, educators, and vendors have all progressed with technological advances. There is a growing momentum that computer visualizations, compared to dissection, offer advantages to learners in terms of accessibility convenience, cost, safety, and versatility [1, 13, 14].

Instructional visualizations, whether in your lecture hall or on your laboratory computers, offer users many visual cues beyond the immediate materials demonstrated. It is imperative instructors are aware that in addition to the explicit information images portray to the learner, there are implicit cues therein which may affect the learning outcomes. Some of the visual information may be superfluous to the topic and objectives, and thus, reduce learning. Please see Table 31.1 for an overview of the characteristics and variability instructional software might take as it pertains to visualization media. The reader should consider where these characteristics occur in his/her own pedagogic approach and how they might affect the learner. As Table 31.1 illustrates, visualizations can vary significantly. Some qualities are apparent like the delivery medium or whether components of the visualization move, but there are deeper perceptual cues that permeate the literature of psychometrics and have been linked, with controversy, to intelligence [15] and definitely to learning. These perceptual cues are important features in anatomical education both for the novice learner and the advanced clinician as they aid observers’ perception of orientation, location, and identification of the material presented. Once these wayfindings are achieved, the learner must then determine if the presented image is coherent with existing mental models they have formed. Indeed, as digital media steadily creeps into all aspects of modern anatomical education, it is important that the visualizations included in our teaching materials do not undermine good pedagogic intentions.

The viewer’s spatial visualization ability may significantly influence the quality of information an image presents to the viewer. Importantly, an individual’s spatial ability dictates how difficult

| Table 31.1 Characteristics of instructional visualizations and the inherent variability with each characteristic |
| --- |
| Visualization characteristic | Variability or type of visualization |
| Delivery medium | Visualizations can be presented on a page, on a large screen for multiple viewers, or on a portable device (laptop, tablets, or smartphones) |
| Dimensionality | Visualizations can be presented in 2D (line drawing), as a 3D-rendered image with shading, apposition, and perspective, or may be stereoscopic 3D rendering requiring apparatus to view appropriately |
| Realism | Visualizations can be highly realistic (photos or videos) or may be of low realism like line drawings or schemata |
| Interactivity | Images can be a series of drawings paced by the learner, a movie with pause function, and a computer-generated image where users manipulate information within the image or may simple be a noninteractive movie or drawing |
| Dynamism | Images may be static or involve moving components |
it is for the viewer to extract pertinent information from the salient features of the visualization. Spatial ability refers to an individual’s ability to search the visual field; apprehend the forms, shapes, and positions of objects as visually perceived; create mental representations of those forms, shapes, and positions; and manipulate such representations “mentally” [15]. In other words, an internal representation of a perceived object or scene must be created and maintained in working memory in such a way that mental manipulations are possible [16]. As the reader can imagine, this is not an easy task for all individuals and it can impact learner comprehension. Garg and colleagues investigated how students performed using a digital model of the carpal bones when asked to study and learn from key views versus interactive or multiple rotational views of the model [17]. Their results did not support the concept that students learn better with rotational virtual reality-type models. Indeed, they “cautioned” educators to carefully consider the inherent characteristics of the models before deciding to use virtual reality-type images in a pedagogical approach [17, 18]. Levinson et al. suggest learner control of multiple views in more complex digital models of a structure, such as the brain, may impede learning, particularly for those with relatively poor spatial ability [19]. Despite caution flags, Brewer et al. suggest that learner control of models might attract novice learners, as the idea of “exploration” of virtual models leads to greater spatial comprehension [20]. Nguyen and colleagues suggest that an individual’s spatial ability affects comprehension that involves not only object orientation recognition but also understanding how a 3D structure appears both in shape and locality in cross-section [21]. Importantly, their results demonstrate that not all images are created equally as persons with lower spatial ability take longer to complete tests and make more mistakes. Finally, even anatomical testing validity may be inadvertently undermined by incorporating questions that utilize images in their answers as image use significantly influences both test item difficulty and the question’s discriminatory power [22]. From this sampling of anatomical pedagogic research, it is clear that the old adage “a picture is worth a thousand words” is indeed true! However, not all viewers will form the same words nor divine the same meaning.

Good teachers are constantly exploring different methods to attract the attention of the entire class. In efforts to mediate perplexed students, technology has led us to believe that dynamic multimedia-embedded “PowerPoint” presentations are the best way to exude information and the learner will simply soak it up. Complex images, movies, 3D digital models, and even personal augmented reality are becoming increasingly accessible to the anatomical landscape of the classroom or lab. Are educators moving in the right direction with good pedagogic principles? Or is the development of tools through technology leading our teaching? It is paramount that educators understand the impacts that these sexy, futuristic, and attractive tools of our educational arsenal have on our students. In some cases, effective teaching may require large powerful tools, while at other times more subtle approaches could be much more useful.

**Increased Cognitive Load Diminishes Learning**

As the field of research in anatomical pedagogy broadens, new research paradigms are emerging which explore previously ignored facets of our educational practice. The concept of learner’s cognitive load capacity, and in particular, the consequences on individual’s working memory, is one area of image-coupled pedagogy that is receiving increasing attention. The term “cognitive load” was coined in the late 1970s by John Sweller and has since been the subject of much research and refinement [23, 24]. As digital tools have made their way to the educational mainstream, the theory of cognitive load has undergone changes to incorporate the use of multimedia technologies for learning and instruction.

Richard Mayer is perhaps best known in cognitive psychology for his timely work describing the theory of cognitive load and how it is applied to multimedia intersecting with knowledge translation [25]. Interestingly, even in the early days of multimedia in education, Mayer expresses
concern over how much information a learner can process given the novel and increasingly rich methods offered through multimedia channels [26]. Mayer demonstrates that creators and users of multimedia learning should reduce cognitive loads on our learners to enhance learning [27]. But what is cognitive load? Chandler and Sweller [28] suggest that learning can be significantly reduced by multiple drains on the cognitive resources of the learner, hence the electrical analogue of a load. Built on the work of Sweller [29], Mayer [8] suggests a triarchic model of cognitive load highlighting intrinsic, germane, and extraneous cognitive processing, describing how each can separately draw upon the learner’s cognitive capacity.

A central tenet of cognitive load theory, as it pertains to multimedia, is that learners engage in different cognitive processing [27, 30, 31] depending on the type and quality of the learning materials presented [32]. Each process draws on the individual’s cognitive capacity [25]; thus, some information may be quickly understood and organized into long-term memory for one subset of learners but may be arduous for others. The goal for educators is to adopt proven methodologies and translate these approaches into their own specific style in order to make learning easier—yes easier—for the student! Three types of cognitive load are described below. In each case, the goal is to mediate loads appropriately through the purposeful design or use of our teaching materials and pedagogic approach to enhance learning.

The first form of cognitive load is termed intrinsic; it arises from cognitive processing required to apprehend and make sense of novel material. Intrinsic load pertains to the perceived complexity of the “stuff” introduced to the learner. The intrinsic load is described as being an integral part of the learning task that results from interactivity among the elements of to-be-learned materials. This component of cognitive load cannot be easily reduced without impacting the learning objectives [27]. In anatomical education, this “essential” processing is often viewed to be a large hurdle for the novice as the plethora of terms relating not only to the nomenclature but also to the orientation, location, and cross-sectional planes, and even function are often overwhelming. All is not lost, however. Table 31.2 illustrates three principles of essential processing that contribute to intrinsic load, and some general applications educators might follow to mediate intrinsic overload. Readers should recognize that despite using images in their anatomical lessons, the principles of modality and segmentation are important guides to effective presentation and can be achieved with attention to dosing of elements in their visualizations. In the latter part of this chapter, an example of segmentation of images is presented. Lastly, the principle of pretraining is often overlooked in anatomy but can be effectively accomplished utilizing good lecturing principles, whereby the leader of the discussion presents a quick plan for the learning activity incorporating concepts from the previous day.

The next type of cognitive load is termed germane or generative (Table 31.3), and it is related to cognitive processes dedicated to making sense of the materials, organizing it mentally, and inte-

| Principle   | Application                                                                 |
|-------------|-----------------------------------------------------------------------------|
| Pretraining | Begin lessons with an overview of important terms, overall relationships, and explain any jargon you might use |
| Segmentation| Present materials in short sections rather than in one continuous unit       |
| Modality    | Use images coupled with spoken words rather than a long string of written words during presentations |

Table 31.3 Principles of generative processing and applications to encourage the process

| Principle   | Application                                                                 |
|-------------|-----------------------------------------------------------------------------|
| Multimedia  | Present words and images rather than words alone                             |
| Personalization | Use conversational speech rather than formal speech when presenting         |
| Voice       | Present speech with natural human voice rather than a computerized one in online scenarios |
| Image       | Include speaker’s image on the screen from time to time if materials are being presented online |
grating it with any prior knowledge and mental schema the student might already possess [33]. Application of germane processing principles in face-to-face scenarios will foster good generative processing in your students. Generative load is often attributed to learner motivation and preference. Therefore, if the educator can facilitate these applications, learner attention will improve, and more information will be appended to the students’ long-term memory as knowledge.

The last form of cognitive load is called extra-neous load (Table 31.4). It refers to the cognitive processing that does not serve the objective of the learning exercise and is mostly imposed by inappropriate approaches that ignore working memory limits. As educator’s materials surpass thresholds in students’ extraneous load capacity, the effects are manifested by learner confusion and/or frustration and therefore need to be minimized. The overall goal of educators is to manage intrinsic loads, reduce extraneous load, and encourage environments that facilitate germane loads.

| Principle         | Application                                                                 |
|-------------------|-----------------------------------------------------------------------------|
| Coherence         | Delete extraneous words, sounds, or images                                  |
| Signaling         | Highlight important terms and images                                        |
| Redundancy        | Remove redundant captions from narrated animation                          |
| Spatial contiguity| Position critical terms next to images                                      |
| Temporal contiguity| Present corresponding words and images simultaneously                       |

### Methods to Reduce Cognitive Load Using Visualizations

In order to understand cognitive load as it pertains to lectures, presentations, and multimedia in general, three assumptions are made. These assumptions come from cognitive science and form the basis of how the human mind works with respect to information processing [27]. For a complete review, the reader should see Mayer’s cognitive model of multimedia learning [8] and refer to Fig. 31.1 for a pictorial overview. Briefly, the first assumption treats the sensory pathways related to seeing and hearing as dual channels where learners process the inherent sensory information in each channel separately yet simultaneously. The second assumption is that of capacity; learners have very limited capacity to process information in each channel at one time. Finally, the assumption of active processing indicates that learning is not, and cannot, be a passive process. Importantly, learning will not occur unless attention is given to relevant material [34] using vision and audition in what Mayer refers to as sensory memory. Sensory memory is of very short duration and supposed unlimited capacity that attends to all environmental sounds, images, words, etc. Words and pictures are selected from our attention and brought into the limited working memory component of cognition. The working memory of an individual has temporary and limited storage that temporarily holds and manipulates the selected verbal and visual information. The information in working memory must be rapidly organized, contrasted, compared, and worked into mental models [33]. The mental models are either formed anew or may be integrated with schema, already present in the form of prior knowledge. Prior knowledge of a subject differentiates novices from experts. The learner appends this newly constructed information to their long-term memory, which is thought to be of unlimited capacity [27, 30].

In order to demonstrate methods aiming to decrease cognitive overload, an example of an introductory lesson on the heart is employed. In the accompanying figures, the instructor is giving an overview of the heart chambers and the valves separating them. In Fig. 31.2, examples of potential cognitive overloads are presented, while in Fig. 31.3, the multimedia approach was altered to reduce cognitive load. The following paragraphs outline what the educator can do mechanically with the visualization during a demonstration or lecture. Realize that this is a static picture; the importance of the following paragraphs will be heightened should the educator utilize one of the
many software programs available on the market that are dynamic in the sense that they can move or can strip layers off the anatomy, in essence, change in front of the learner.

In Fig. 31.2, the instructor utilizes an actual photograph of the mammalian heart with numbers close to pertinent, but somewhat ambiguous, locations. The numbers then refer to a lengthy legend below where information is presented. It may be tempting in your slides or demonstrations to include dense information but doing so will only serve to increase cognitive load on the learner. The increased extraneous load of Fig. 31.2 will lead to decreased learning as the multimedia principles illustrate low coherence as there is too much information, lack of signaling as the numbers are next to ambiguous structures, and poor spatial contiguity characteristics as explicatory text is distant from the picture (see Table 31.4). The inclusion of excessive information on one’s slides is a common mistake and should be avoided at all costs. Instead, the instructor might commence with the photograph to demonstrate how complicated the actual structures appear in vivo (Table 31.2—overview). The instructor would then transition to simplified diagrams (increasing coherence) in a very prescribed and stepwise fashion giving only parts of the diagram sequentially (Table 31.2—segmentation), using good oration (Table 31.2—modality), and present the diagram and perhaps a few key visual examples to learners as demonstrated in Fig. 31.3a, b. Utilizing a “less is more” approach with multimedia takes advantage of both the visual and auditory (dual) channels in the learner and enables better cognitive processing, thus

![Multimedia Presentations](image)

**Fig. 31.1** Illustration of the cognitive theory of multimedia learning. The learner (*bottom right*) participates through apprehension of multimedia where dual sensory channels bring sensory information to the working memory of the learner. Information in the working memory must quickly be organized and encoded into mental models for organization in long-term memory.
cognitive load reduction. Taking advantage of maximizing essential processing principles (Table 31.2), the learner can then better attend to key information, rather than trying to decipher the message. Utilizing a simplified visualization while making use of the spoken word accompanying these images effectively achieves the effect of modality in a lecture scenario.

In concert with the modality effect, good instructors also know how to pace their messages
and visual materials. The first approach affecting pace is the segmentation principle (Table 31.2). Segmentation, sometimes called chunking, can be a temporal factor where the instructor simply needs to slow down to employ purposeful repetition of important information (verbal signaling), highlighting important structures (verbally and visually) or giving pertinent analogy for the students to both see and hear (modality) information presented in chunks. Instead of an overwhelming image (Fig. 31.2), educators should consider simplifying visuals and using sequential figure components that parse the learning materials into a step-by-step fashion (Fig. 31.3a, b) matching visual representation with auditory explanation (spatial and temporal contiguity). By combining the principles of segmentation, modality, and contiguity, educators enable learners to “chunk” information more efficiently [6]. For the learner, chunking doses the amount of information present in working memory, aiding information transition to long-term memory (Fig. 31.1).

Often, to reduce cognitive load, multimedia images and accompanying oration need to be simplified and streamlined in a process Mayer and Moreno describe as weeding [27]. The goal of weeding is to eliminate potentially interesting but extraneous material to reduce the processing of the ill-fated extraneous overload. By weeding out many of the words in Fig. 31.2, or potentially distracting materials such as background noises, or poor video clips, the coherence principle (Table 31.4) is applied and the learner can move more information from working memory to long-term memory. Contrast the image and accompanying information in Fig. 31.2 with that of the images in Fig. 31.3. This process may be difficult for educators, for as we become proficient in a discipline, the discipline and its intricacies tend to take on an ego of its own, and we convince ourselves that students need every individual detail. This simply is not true and Mayer describes this information as “seductive details” [35], and these details should be removed to enhance learning.

Finally, as many courses are moving to online formats where video and narration is often used, educators need to keep narration in time with the presentation and to avoid overly repetitive delivery. Mayer refers to this approach as the temporal contiguity principle [36] (Table 31.4). Although elaborate digital demonstrations may be tempting, they hold limited quantitative pedagogical support, for by their nature, they introduce additional and different cognitive demands on the novel learner.

**Fig. 31.3 (a, b)** Depiction of a simple heart illustration that might be used in multimedia environment, including lectures. These diagrams incorporate multiple aspects of cognitive load-reducing techniques that affect extraneous processing. This simple set of diagrams would be part of a series of diagrams that are “built” in a stepwise fashion for students that introduce one element (label) at a time. They would be used in concert with good presenter narration with meaningful repetition of the important terms geared to the objectives of the lecture or multimedia exercise. The use of color and transparency should also be incorporated to make borders of adjoining anatomy clearer for the learners. This approach incorporates coherence, signaling, and spatial and temporal contiguity (Table 31.4), enabling students to chunk information and link increasing pre-knowledge with new information.
Students with more advanced base knowledge will not fall victim of high cognitive loads for they already have prior knowledge and append new information to schema in long-term memory [37]. Lowe questions the widely assumed learning edge animated graphics have over static graphics in a learning environment. Lowe suggests that cueing, in the form of “specific strategies and targets,” need to be in place in order for learners to create accurate mental representations from interactive animations [38]. If the use of complex visuals or software is deemed necessary with novel anatomists, these visualizations should be well explained within the context of the lesson or used to provide a summary of the material in question rather than a vehicle by which the information is introduced to the students.

**Summary**

To consider multimedia visualizations as ubiquitous tools for successful pedagogy in anatomical education is overly simplistic and incorrect. Much hinges on the base knowledge of the learners, and the goal of the educator is to meet the objectives of the course or activity while challenging the learner. Uses of multimedia that are too wide in the spectrum between the basal needs or challenges to the learner will result in boredom or confusion, respectively. In either case, learning will decrease. Addressing the pertinent anatomical details in accordance with the objectives is truly important, but it is equally important to apply strategies that will enhance learning. The use of multimedia has complicated the challenge to educators, but enhanced learning can be achieved by careful material preparation and presentation with cognitive load in mind. Good instructional methods can be successful across multiple forms of media (face-to-face and online) and any discipline [35]. These methods can be summarized to four short rules that maximize learning:

1. Pay attention to the cognitive loads generated with your learners. The tools (programs, presentations, pictures, and words) will affect cognitive load. **Less is always more.** That is, less “cognitive load” will yield more “learning.”
2. Orate to the ears of the learners and demonstrate to the eyes. Use our two main sensory channels (dual channels) to your pedagogic advantage.
3. Chunk, highlight importance, and pace your presentations using multimedia so the learner is not overwhelmed.
4. Simple visualizations (non-dynamic line drawings) with proximal labels that are color-coded are the best place start with new learners. As the base knowledge of your learners rises, so too can the complexity of your demonstrative tools.

Educators should strive to simplify all aspects of their multimedia use to reduce cognitive load, in particular extraneous load [8] as it is counterproductive to the objectives of their overall mission as a teacher. Multimedia design principles are dynamic and will be heavily influenced by the experience of the learners [39] as advanced learners can draw upon previous knowledge more readily [37], which the instructor should be aware in order to adjust the visualization, language, and pace accordingly. Just as lecturers attend to the verbal detail given to our class, care must be also exercised as to what and, importantly, how we demonstrate to the class as well. By paying attention to the aforementioned principles of multimedia learning, and by organizing visualizations accordingly, regardless of the tool involved, educators will find student satisfaction and success to rise.

As educators in an increasingly fast-paced and digital society, it is important to stay abreast of novel and evidence-driven pedagogic principles and practices. We should constantly weigh ongoing practice with our previous experience in the face of ever-changing student expectations and technology. Until technology is nimble and adaptive to the multitude of learner styles [40], we as educators are the only intelligent buffer that is able to modify our approach to support deep learning in all our learners.
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