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Message from the President of HAPS A Thirty-Year Retrospective

In 1987, the genealogical tree of mitochondrial DNA made the news, showing common descent of all human populations from Africa. Also in 1987, the first of what would become the HAPS annual conference was held at Triton College in Illinois. HAPS has been meeting every year since then, and that makes this our 30th annual conference. From that first year, the format of two days of content updates, two days of workshops, and one day of local field trips has been our standard format. I’d like to put our 30-year history into perspective, in terms of advances and discoveries in biology during the same period. All my selections come from Science Timeline (http://www.sciencetimeline.net, through 2001) and InfoPlease (http://www.infoplease.com, 2002-present) and my history of HAPS comes from our own “History of HAPS” page, at http://www.hapsweb.org/?page=detailed_history.

The second Anatomy & Physiology Workshop at Triton College in 1988 led to the formation of HAPS, with the constitution approved at the 1989 meeting at Truckee Meadows College. The same year, W.A. Devane discovered the cannabinoid receptor, which is the most common G-protein coupled receptor and almost as abundant as the glutamate receptor.

In 1989, the DNA of the centriole-kinetosome was discovered, and the theory concerning simulators and inhibitors of angiogenesis in tumors was proposed. The 1989 HAPS meeting, in Reno, was the site of the official formation of the society. In 1990, the first gene transplant was performed on a human, and it was demonstrated that genes from one species would work in a different species. SRY, on the Y chromosome, was isolated. The chemical that would become Viagra was patented. Gary Johnson hosted the fourth annual HAPS meeting in Madison, Wisconsin.

My first HAPS meeting was San Diego, in 1992, and that year, the effect of thalidomide was determined to be inhibition of angiogenesis. The HAPS electronic bulletin board was set up by Mildred Galliher, and the C&I committee published the HAPS course guidelines. In 1993, apolipoprotein E was identified. HAPS met in Beaumont, and I was on the board as incoming secretary-treasurer. I remember that conference well; I brought my infant daughter (and a “nanny”), although I was not the first to do that! HAPS established its comprehensive exam that year.

By 2000, Craig Venter’s team had sequenced the genome of Drosophila melanogaster, finding equivalent genes to 60% of those known to cause disease in humans, including p53. The HAPS meeting was held in Charlotte, NC. In 2001, HAPS held a memorable meeting in Maui, and the human genome was published. In 2002, the genomes of malaria, mosquito, and mouse were published; HAPS met in Phoenix. In 2003, the genome of the human Y chromosome was published, and HAPS met in Philadelphia. In 2004, the remains of Homo floresiensis were found. HAPS met for a second time in Canada, this time in Calgary. In 2005, HAPS met in St. Louis.

In 2006, HAPS-I was established. The results of an eight-year study were announced; a low-fat diet does not reduce the risk of heart disease, cancer, or stroke. In 2007, two teams announced the success of efforts to form embryonic stem cells from non-embryonic cells. In 2008, the complete genome of the normal and cancer cells of a single individual were sequenced and compared. In 2009, a judge ruled that there is no link between autism and vaccines, in a case brought forward by families seeking compensation from the federal vaccine-injury fund. The HAPS Conference moved from Austin, to San Diego, to New Orleans, to Baltimore.

In 2010, the HAPS Foundation was established; HAPS met in Denver. That year, researchers determined that SIV, the simian precursor to HIV, has a 30,000-year history on this planet. The Nobel Prize for Physiology or Medicine was awarded for discoveries in immunity. The HAPS Conference was held in Victoria in 2011 – another successful Canadian meeting! In 2012, genetic switches were found in what had originally been dismissed as “junk DNA.” HAPS met in Tulsa, then in Las Vegas. In 2014, the devastating Ebola outbreak hit West Africa; HAPS met in Jacksonville, Florida. Following the HAPS Conference in San Antonio in 2015, the 30th Annual HAPS Conference will be held in Atlanta in 2016.

A lot has happened in the last 30 years! This summary doesn’t address the fond memories and dedicated efforts of HAPS members and their allies. I hope you all are able to join us in Atlanta to continue our tradition of active involvement in our profession, together with the warm camaraderie that brings us back year after year.

About the Author

Dr. Betsy Ott has been teaching at Tyler Junior College, in east Texas, since 1982. Betsy completed her B.S. and M.S. degrees in Biology at the University of Alabama, and her Ph.D. at Stephen F. Austin State University in Nacogdoches, Texas. She has completed several HAPS-I courses, contributed to several annual and regional HAPS meetings in Texas, and served as HAPS secretary-treasurer. She is currently HAPS President.
Using Role-Playing Simulations to Teach Respiratory Physiology

Kerry L Hull, PhD
Department of Biology, Bishop’s University, Sherbrooke, Canada

Abstract
Understanding the principles of pulmonary ventilation poses a significant challenge for many students, and thus a particular challenge for physiology educators. This paper describes a role-playing simulation that can help students master the intricacies of the pleural membranes as well as the mechanics of ventilation. Concentric circles of students represented the ventilatory muscles, the thoracic wall/parietal pleura, and the visceral pleura/lungs. Under the direction of the audience members, student actors were able to simulate the structural relationship between the pleurae, the impact of pneumothorax, and the volume and pressure changes involved in inhalation, quiet exhalation, and active exhalation. Pre- and post-testing as well as exam performance revealed that most students were able to master the relevant concepts, and most students perceived the activity as both useful and enjoyable. Thus, whether involved as actors or advisors, students can clarify their understanding of cause-and-effect relationships involved in ventilation by performing this activity.

Key words: ventilation, role playing, simulations, physiology, respiratory system

Introduction
The benefits of incorporating active learning activities into physiology courses are now well documented by empirical studies and supported by cognitive science (Michael 2006). For instance, Freeman et al. (2014) observed a 55% decrease in failure rate and half of a letter grade increase in grades in classes including at least some active learning compared with traditional lecture classrooms. However, the availability of appropriate resources is often a barrier for faculty hesitant to switch away from a lecture format (Michael 2007). Gurung and Schwartz (2009) speak of an “instructor’s toolkit”; a spectrum of classroom techniques that instructors can exploit to match the best technique for each situation. Role-playing simulations, in which students play the role of physiologic elements such as hormones or enzymes and enact different processes, can be one such tool. Experiential learning theory supports the use of this activity type, since it involves multiple learning environments (thinking, feeling, behaving (doing), and perceiving) (Kolb, and Kolb 2005). Simulations exploit sensory modalities, such as touch and kinesthesia, which are not used in other activities and modes of information delivery. Role-plays are also highly motivating and they can provide immediate feedback (van Ments, 1984).

The literature contains relatively few examples of role-playing simulations relevant to physiology. Yucha (1995) used role-playing (described as improvisation) throughout the course, beginning with very simple improvisations and culminating in more complex simulations orchestrated by the students themselves. The technique gathered positive student feedback but did not study concept mastery directly. A more recent measure by Sturges (2009) compared a traditional lecture with a role-playing activity teaching protein synthesis. A post-test revealed no difference between the two techniques in terms of concept mastery, but students performing the role-playing activity reported greater engagement. Other excellent simulations demonstrate the cross-bridge cycle (Meeking, and Hoehn 2002), PTH and calcium balance (Hudson 2012), glycolysis and the Krebs cycle (Ross et al. 2008), and mitosis (Wyn, and Stegink 2000).

The role-plays described in this simulation involve two potential modes of involvement – cognitive and physical (Sturges et al. 2009). Students who participate physically come to the front of the class, and choose (or are assigned) a particular role to enact. The remainder of the class participates cognitively, by acting as members of support groups for the actors. The support group(s) predicts how the simulation will proceed under various circumstances, and then provide advice to the actors as to who does what, and when. The actors can, of course, participate both cognitively and physically; however, they can attribute any incorrect actions on their part to the support group members and thus feel less performance anxiety. This activity thus fulfills multiple aspects of the Universal Design for Learning paradigm, which encourages instructors to provide multiple means of representation, evaluation, and engagement (Rose et al. 2006). Simulations represent concepts using visual, auditory, and even kinesthetic modalities, and provide students with the autonomy to choose how they will engage in the activity.

Role-play simulations may be particularly useful in the area of respiratory physiology, which is rife with misconceptions and difficult concepts (Wilson 2008). The activity described in this paper asks students to role-play the structural relationship between the pleural membranes, the impact...
of a pneumothorax, and the events of ventilation. As summarized in Table 1, the activity goals are aligned with the learning objectives/outcomes of the American Physiological Society and Human Anatomy and Physiology Society (Carroll, 2012; Human Anatomy and Physiology Society). In this article, I begin with a brief discussion of the conceptual underpinnings of the activity. Readers are referred to the many excellent anatomy and physiology textbooks currently on the market for an expanded explanation of the presented concepts (Boron and Boulpaep, 2012; Marieb and Hoehn 2015; Silverthorn et al., 2015).

**Table 1: Learning Objectives.**

<table>
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<tr>
<th>HAPS Objective (Mechanism of Pulmonary Ventilation)</th>
<th>The Pleural Membranes and Pneumothorax</th>
<th>Pulmonary Ventilation</th>
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<td>6. Describe the forces that tend to collapse the lungs and those that normally oppose or prevent collapse.</td>
<td>1. Define and state relative values for atmospheric pressure, intrapulmonary pressure, intrapleural pressure, and transpulmonary pressure.</td>
<td>4. State Boyle’s Law and relate this law to the specific sequence of events (muscle contractions/relaxations and pressure/volume changes) causing inspiration and expiration.</td>
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**The Pleurae and Pneumothorax**

The first part of this simulation targets structure-function relationships of the bilayer pleural membrane. The parietal pleura lines the thoracic cavity, covering the chest wall and the diaphragm. The visceral pleura covers the lungs. The virtual space between them, the pleural space, is filled with pleural fluid that adheres the two pleural layers together. The thorax grows faster than the lungs during embryonic development; thus, the lungs are stretched to fill the thoracic cavity, and the elastic recoil of the lungs pulls the thorax inwards. These two forces balance each other exactly when the lungs contain their functional residual capacity.

Pneumothorax is the presence of air in the pleural space, resulting from damage to the chest wall (e.g. from a penetrating chest wound) or to lung tissue (e.g. from excessively violent coughing). Air disrupts the interaction between the visceral and parietal pleurae, so the lung’s elastic recoil pulls the lung inwards and the chest wall’s elastic recoil pulls outwards. The lung “collapses” to its unstretched size, and the chest wall becomes slightly larger. Pneumothorax can be complete, in which the affected lung completely loses contact with the chest wall, or incomplete.

**Events of Inspiration and Expiration**

The events of pulmonary ventilation rely on Boyle’s law, which states that volume and pressure of a gas are inversely related in a closed compartment. Thus, by changing the volume of the lung space, intrapulmonary pressure changes in relation to atmospheric pressure. The resulting pressure gradient causes air to flow. A breathing cycle begins with contraction of the inspiratory muscles. These muscles expand the thoracic cavity, pulling the parietal pleura ever-so-slightly away from the visceral pleura and expanding the volume of the intrapleural space. This increase in volume decreases intrapleural pressure, increasing the transmural pressure gradient. This increased gradient moves the visceral pleura (and thus lung tissue) outwards, resulting in decreased intrapulmonary pressure. Since intrapulmonary pressure is lower than atmospheric pressure, air flows into the lung down the pressure gradient. (Note: instructors that do not discuss intrapleural and transmural pressures can simply mention that the parietal pleura pulls on the visceral pleura, thereby expanding lung volume).

More dramatic inhalations use stronger contractions and additional muscles to produce larger volume, and thus pressure, changes. Expiration occurs when the inspiratory muscles relax, permitting the lungs to recoil back to their pre-inhalation size. This decrease in volume increases pressure above that in the atmosphere, and air exits the lungs down the pressure gradient. Active expirations recruit additional muscles to accelerate the volume (and thus pressure) changes resulting from the lung’s elastic recoil, and can additionally reduce lung volume below the functional residual capacity.

**MATERIALS AND METHODS**

The study population consisted of thirty-four students in their third or fourth year of a B.Sc. program, specializing in Biology, Neuroscience, or Biochemistry. The course was the second in a series of two Animal Physiology courses required of the Biology and Biochemistry students, but optional for Neuroscience students, and had two Cell Biology courses as prerequisites. The class format involved numerous active learning activities, but it was not “flipped”
in that the lecture was usually the first exposure to the material. The simulations were done before the concepts were covered in a lecture format. The class was taught in a small amphitheatre with swing-out tables.

**Basic Simulation Protocol**

For each simulation, student volunteers were provided with signs indicating their role (e.g. visceral pleura). Since the simulation involves contact between the actors (see Fig. 2, bottom right), students often preferred to be recruited in pairs. The remainder of the class was divided into support groups for each actor. The support groups were asked a question before each simulation trial (Table 2), and were encouraged to direct the actors. Student understanding was monitored before and after the activity using multiple-choice questions (see Figure 3), and each simulation was followed with a debriefing lecture and discussion.

**Role of the Pleural Membranes**

The first simulation investigates the structure and function of the pleural membranes. Between two and four student pairs play the role of the visceral pleura/lung tissue and the parietal pleura/chest wall. Figure 1A illustrates the initial setup. Each dot represents a student's torso, and the arrows represent the student's arms. In the descriptions that follow, the actors are referenced by their roles. In brief:

1. The visceral pleura stand back-to-back; the space created between their backs represents lung volume.
2. Each parietal pleura stands facing a visceral pleura; the space between the “pleural pairs” represents the intrapleural space. Figure 1 shows four sets of students oriented in a circle, but the simulation can also work with only two sets. Students should be reminded that the illustrations and the simulation overestimate the size of the intrapleural space.
3. The pleural pairs stand quite close together and link arms; this linkage represents the adhering force of the pleural fluid. Then, all students lean backwards, representing the inward recoil force of the lungs (visceral pleura) and the outward pulling force of the chest wall (parietal pleura). Students can then visualize the increase in volume (and thus decrease in pressure) within the intrapleural space.
4. Next, students can simulate the impact of a pneumothorax on lung and chest volume, as described in Table 2. After asking the support group question, one or two additional students are recruited to play the role of air. Air breaks the link between a pair of pleural students (i.e. separates their arms). If the students are leaning back, the chest wall should move outwards (representing increased volume) and the lung volume should decrease (Figure 1B).

**Figure 1.** The pleural membranes and the impact of pneumothorax. Each dot indicates a student, and the color of the dot indicates the student’s role. The upper left figure illustrates the positions of the different actors in a healthy lung; the upper right figure illustrates their positions after air enters the pleural space (pneumothorax).
Mechanisms of Ventilation

The second simulation illustrates cause-and-effect relationships during ventilation, and can also be used to illustrate intrapleural pressure changes and transmural pressure gradients. The support group questions and desired sequence of events are summarized in Table 2. In brief:

1. The pleurae resume their initial positions, as shown in Figure 1A.
2. For each pleural pair, an additional student is recruited to play the inspiratory muscles (diaphragm, external intercostals). A muscle student stands behind each parietal pleura student. The students can be provided with varying degrees of autonomy in regards to the setup. For instance, the instructor can specify that the four visceral pleura students stand back-to-back, and let the other students figure out where to stand (perhaps under the guidance of the non-acting students).
3. The instructor can then ask the audience to vote on which actor moves first to enable inhalation (Table 2). Eventually, after some discussion and under guidance from the audience, the actors usually arrive at the correct procedure, with inspiratory muscles acting as effectors, pulling on the parietal pleura, which pulls on the visceral pleura, which increases lung volume. Then, and only then, does air enter the lung.
4. The instructor can also direct the simulation in slow motion in order to illustrate intrapleural pressure changes. First, the ventilatory muscles pull back on the parietal pleura. The intrapleural space expands, thereby reducing intrapleural pressure. This reduction in intrapleural pressure creates a transmural pressure gradient that causes the lung to expand.
5. In order to visualize passive (eupneic) exhalations, the students should pause the simulation at maximum inhalation, and support groups should discuss what the actors should do, and in what order. At this point, the inspiratory muscle students are actively pulling outwards on the parietal pleura students, preventing the lung from returning to its original size. As the inspiratory muscles cease pulling outwards, the visceral pleura/lung students “fall” inwards and reduce lung volume. The resulting pressure gradient forces air out of lungs.
6. In order to visualize active exhalations, an additional student is recruited for each pleural pair to represent the internal intercostals and abdominals, and

<table>
<thead>
<tr>
<th>Support Group Question</th>
<th>Pleural Membranes/ Pneumothorax</th>
<th>Pulmonary Ventilation</th>
</tr>
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<tbody>
<tr>
<td>What will happen to lung size and thorax size if air enters the pleural space?</td>
<td>1. Use initial setup. (Fig. 1A). 2. Air breaks the bond between the pleurae (i.e. separates their arms). 3. As the visceral and parietal pleurae release arms, they fall backwards. 4. The chest wall thus expands, and lung volume decreases (Fig. 1B).</td>
<td>1. Add inspiratory muscles to the initial setup (Fig. 2A). 2. Muscles pull parietal pleura outwards. 3. Pleural space expands briefly, then visceral pleura moves outwards. 4. Lung volume increases. 5. Air enters (Fig. 2B).</td>
</tr>
<tr>
<td>Which participant acts first, and what should he/she do? What happens next?</td>
<td>1. Begin with lungs at maximum volume (Fig. 2B). 2. Inspiratory muscles relax, so they no longer offset the lungs’ elastic recoil. Lung volume decreases. 3. Pleural space expands briefly; visceral pleura and chest wall move inwards (Fig. 2A).</td>
<td>1. Begin with lungs at maximum volume (Fig. 2B). Add expiratory muscles (not illustrated). 2. Inspiratory muscles relax. Expiratory muscles push parietal pleura inwards, and visceral pleura/lungs pull inwards. 3. Lung volume shrinks rapidly.</td>
</tr>
</tbody>
</table>

Table 2. Role-playing Simulation Protocols. Note that the actors are referenced by their roles (i.e. air, parietal pleura).
stands beside the inspiratory muscle actor. As with the previous trial, the simulation should begin at maximum inhalation. The inspiratory muscles release at the same time as the expiratory muscles push inwards. The dramatic and rapid change in lung volume (watch for falling students) causes a rapid and dramatic pressure gradient, and thus increased flow.

7. The simulation should be revisited at least once in a subsequent class, either to reinforce the earlier concepts or introduce new variants. For instance, the reduced lung compliance associated with fibrosis can be visualized by encouraging the visceral pleura/lung students to resist movement during inhalation. The reduced lung recoil of emphysema, conversely, involves the visceral pleura/lung students staying in place during passive exhalation.

**Evaluation**

The effectiveness of the activity was determined using anonymous pre- and post-testing. Students recorded their answers to relevant multiple-choice questions before and after each simulation, so the progress of individual students could be monitored. Longer-term mastery was determined by including the same questions on the midterm, and, in some cases, asking for narrative defenses of their chosen answer. Student perceptions of the specific simulations, and simulations in general, were gathered using anonymous surveys.

**RESULTS**

**Evaluation of Concept Mastery**

In order to investigate the effectiveness of the simulation, students recorded their answers to multiple choice questions related to pneumothorax and to the events of inhalation (Figure 3). Note that the activity and the pre- and post-testing were performed prior to any coverage in lectures or assigned readings. Due to a technical issue, students used an anonymous printed response sheet instead of a personal response system. Of the 34 registered students, 29 students were present in class and completed the activity. Of the five students that chose the incorrect answer to the pneumothorax question prior to the simulation, four students switched to the correct answer after the simulation (Figure 3, left side). The inhalation question proved more difficult for students, with 10 students choosing the incorrect answer pre-simulation (Figure 3, right side). Six of these students switched to the correct answer post-simulation, but two students switched from the right answer to the wrong answer. Two students persisted in the incorrect answer.

The identical multiple-choice questions were asked on the midterm. The inhalation question also had a narrative portion asking students to defend their answer. Thirty-four students wrote the exam; thus, six of these students were not present for the activity. Since the pre- and post-testing was anonymous and I do not take class attendance, it is not...
possible to determine if students choosing incorrect answers were or were not present for the activity. Only two of the 34 students writing the midterm chose the incorrect answer for the pneumothorax question. In both cases, they chose the option that both the chest wall and the lungs would decrease in size in response to a pneumothorax. Twenty-eight students chose the correct answer for the question addressing the events of inhalation, and their narrative answers revealed that they understood the concept. Six students either chose the incorrect answer or were unable to justify the correct answer. Their narrative responses revealed persistent misconceptions regarding the cause-effect relationship between volume changes, pressure changes, and airflow. Four of the six responses correctly referenced the inverse relationship between volume and pressure, but claimed that air flow changed volume, which then changed pressure. For instance, one student concluded “The second answer is wrong because lungs volume will not expand and increase without air coming in first”. A second student claimed, “The lung fills up with air; thus, increasing the volume and decreasing the pressure.”

Evaluation of Student Perceptions

Figure 4 summarizes the data from an anonymous student survey, in which students indicated how strongly they agreed with two statements:

1. The activity helped me understand concepts discussed in class.
2. The activity was interesting/and or enjoyable.

A score of 5 indicated “strongly agree” and a score of 1 indicated “strongly disagree”.

There were 32 responses; thus, three students gave a score for the ventilation activity but were not present for it. Student perceptions of the peer education method (known in my classes as “clickers”) were included as a sort of positive control, since the utility of this activity is well established in the literature (Smith et al. 2009). The peer education method asks students to answer a multiple-choice question using a personal response system. If a significant portion of the class chooses the wrong answer, students are asked to defend their choice to a neighboring student prior to answering the question a second time. In accordance with the literature, students found the technique very useful and quite enjoyable. They found the ventilation simulation to be somewhat less useful, but equally enjoyable. In comparison, the ventilation simulation fared much better than a 2-stage review activity, in which students completed a no-stakes quiz addressing prerequisite concepts alone and subsequently in groups (Maxwell et al. 2015).

The student perception survey also asked students to opine about simulations generally, and to describe reasons why they chose to participate, or not participate, in simulations. Students were allowed to choose multiple options, and space was available for narrative comments. As shown in Table 3, 32 students completed the survey, and only 1 student did not find simulations useful at all. The survey also revealed that about 3/4 of class members preferred watching simulations to performing in them, and that potential barriers to physical participation include shyness (32%) and the physical classroom environment (18%).

Figure 3. Pre-activity and post-activity testing.

Students were asked the same multiple choice question (see Table 1) before and after performing the simulation. The first word of each legend indicates a student’s answer in the pre-test, and the second word indicates the same student’s answer in the post-test. Thus, the “wrong-right” group provided the wrong answer on the pre-test but the correct answer in the post-test. Twenty-nine of the thirty-four registered students participated in the simulation and completed the pre- and post-questions.

Possible reasons for choosing the incorrect answer for the pneumothorax question include an incorrect understanding of the concept of a pneumothorax, or a lack of understanding of the respiratory system. A common misconception is that the thorax and lungs would both decrease in size in response to a pneumothorax. This is incorrect, as the thorax would actually expand and the lungs would get smaller. Therefore, it is important to ensure that students have a clear understanding of the concept of a pneumothorax before assigning the simulation. Some possible ways to do this include providing a brief lecture on the concept of a pneumothorax, or having students complete a quiz on the concept before assigning the simulation.
Table 3. Student Perceptions of Simulations. Students were asked to provide feedback as to why they do, and do not, like to participate in role-playing simulations. Students were free to select multiple answers.

<table>
<thead>
<tr>
<th>Answer</th>
<th>Percentage (number) of Students Choosing Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>For me, acting as a participant helps me understand the process better than watching the simulation.</td>
<td>21% (7)</td>
</tr>
<tr>
<td>For me, watching the simulation is more useful than being a participant.</td>
<td>71% (24)</td>
</tr>
<tr>
<td>I wouldn’t mind participating, but it’s hard to get out of the chairs in Molson 10 (the classroom).</td>
<td>18% (6)</td>
</tr>
<tr>
<td>I don’t like to participate because I’m shy.</td>
<td>32% (11)</td>
</tr>
<tr>
<td>I don’t like to participate because of cultural reasons.</td>
<td>0% (0)</td>
</tr>
<tr>
<td>I like being part of a support group that votes on how the participant should act.</td>
<td>21% (7)</td>
</tr>
<tr>
<td>I do not find it useful to participate or watch simulations.</td>
<td>3% (1)</td>
</tr>
</tbody>
</table>

DISCUSSION

Role-playing simulations can effectively clarify dynamic relationships between structural components; in this case, the relationship between the chest wall, the pleural membranes, and the lung. While figures can teach students to label these components, this simulation helps students understand how recoil forces of the chest wall and lung tissue would pull the membranes apart if not for the adhesive power of the pleural fluid. They can then observe and, in the case of actors, experience what happens if the adhesion is lost due to air entering the pleural cavity. The post-simulation testing and exam results revealed that approximately 95% (32 out of 34) students were able to master the HAPS/APS objective relevant to the pleural membranes.

Role-playing simulations can also help students distinguish between cause and effect. The second part of the simulation attempted to address the misconception that the flow of air causes lung volume to change (instead of vice versa), perhaps reflecting students’ experience in inflating balloons. The incorrect answer to the ventilation question (“Lung volume changes because air enters the lungs”) was chosen by ten students in the pre-test. Two other students chose the wrong answer in the post-test, and five students were absent from class; thus, this misconception could be conceivably shared by approximately half of the class population. Only six students persisted in this misconception on the midterm exam. Since the pre- and post-testing was anonymous, it is impossible to say if these students participated in the simulation and in the post-simulation debriefing. The students that correctly answered this question were also able to explain the causal links in the series of events beginning with muscle contraction and finishing with air flow; thus, there was evidence that students developed some degree of conceptual understanding instead of simply memorizing the answer.

Figure 4. Student Perceptions. Student perceptions of the ventilation simulation, the peer education method (“clickers”), and a 2-stage review activity were compared using an anonymous survey. Thirty-two students completed the survey. A. For each activity, students indicated how strongly they agreed with these two statements: 1. The activity helped me understand concepts discussed in class (blue bars). 2. The activity was interesting and enjoyable (red bars). A score of 1 indicates “strongly disagree”, and a score of 5 indicates “strongly agree”. Data is provided as mean +/- S.E.M. B. The number of students selecting each score for the first question, which indicated the usefulness of the activity.

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I hypothesize that this degree of mastery was possible because students enacted the series of events in order. In the simulation, students are reminded that the ventilatory muscles are the only active players in the situation. If students try to have air move first, it becomes quickly evident that nothing is propelling the air.

The simulation was performed before students had covered the relevant concepts in a lecture or reading. This decision reflects my emphasis on General Models (Modell 2000); students are encouraged to view pulmonary ventilation as a variant of the general model of flow that was already discussed in the context of diffusion and blood flow. It is also in line with the constructivist theory that students remember best when they construct the knowledge themselves (Eberlein et al. 2008). In retrospect, it might have been beneficial for students to do the simulation after they had a basic knowledge of the pleural membranes. Moreover, I did not show the students the representations of the simulations (Figures 1 and 2), and one student commented that this would have been helpful. Chinnici (2004) emphasizes the importance of the debriefing period, and provided students with a printed handout linking the model with the concept in their simulation of the events of mitosis. Showing the students representations before, during, and/or after the simulation may alleviate the confusion noted by students during the simulation. Equally important in alleviating student confusion is labeling the actors. I have used simple signs that students hang around their necks using string. Other investigators have used labeled ball caps (Chinnici et al. 2004) or colored pinneys (jerseys) (Wyn, and Stegink 2000).

In an earlier study of biology role-playing simulations, Yucha et al. (1995) claimed that “It is widely accepted that we only understand the complexities of a learning situation when we are personally involved in it”. Sturges (2009) proposed the term “physical involvement” to describe students performing the simulation, and promotes “cognitive involvement” of non-actors by encouraging all class members to participate in the post-mortem discussion. The simulation style described herein attempts to deepen the cognitive involvement of non-actors by giving them responsibility for the actions of the actors. Theoretically, this modification should increase student willingness to volunteer for the acting roles, since there will less worry about doing the wrong thing. Indeed, one student attributed his/her hesitancy to the fear of doing something wrong that will be noticed by the class. However, while 71% of students favored watching simulations, only 21% found it useful to act as an “advisory group” to the actors. While this percentage was lower than I would have liked, one student wrote that “…when I am observing and giving the actors instructions (it) makes me determine if I am on the right track or not.”

Universal design for learning theory underlines the importance of student autonomy; that is, allowing students to chose to be actors or not (Rose et al. 2006). In this study, 71% of the participants reported that they found it more useful to watch simulations than to be involved in them. Students have reported that simulations can seem confusing when they are one of many moving parts, and that the sequence of events and relationships between the parts become clearer when they watch from a distance. Thus, it can be useful to repeat the simulation at least twice, so that students can choose to both participate and to watch. Repeating the simulation multiple times, if possible during multiple classes, is also beneficial in itself, since students have reported that they only understood the simulation the second time.

Nevertheless, obtaining enough willing participants to run the simulation can be a challenge. One aspect is the physical environment; students appeared to lack the energy to put aside their books and winter coats and struggle out of their seats in my amphitheatre-style classroom. I have anecdotally noted that providing participants with small chocolate bars or oranges can partially correct for physical fatigue. Student personality certainly plays a role in student reticence: Nearly one-third of the students selected the option “I do not like to participate because I am shy”. This resistance may, in part, reflect the fact that students are conditioned to take a passive role in the classroom (Felder, and Brent 1996; Modell 1996) and that students find that active learning takes too much effort (Qualters 2001). It is hoped that the increasing prevalence of “flipped classrooms” and the emphasis on active learning techniques will alleviate this resistance, but it is still highly pervasive, in my classes at least. If sufficient trust exists between the students and instructor, it is possible to “volunteer” students who would like to participate but are too hesitant to volunteer. Generally, however, simulations work best when students have control over their mode of involvement.

Adequate volunteer rates require the establishment of a safe classroom environment. The act of walking to the front of the classroom is quite intimidating for some students, and any whiff of “acting” may be scary. Yucha (1995) suggests that role-playing simulations be incorporated throughout the course, beginning with simple improvisations modeled by the instructor, progressing through increasingly complex simulations under partial student control, and culminating in the development and performance of role plays entirely by the students. It can also be useful to take the opposite approach, in which an early simulation involves all students and thus removes the volunteering aspect (Nickerson, 2007). As with all active learning techniques, the instructor can set the stage for optimal student involvement in the first class meeting (Boudrie 2011, Modell 1996).

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The findings of this study thus support the utility of role-playing simulations for teaching the mechanics of ventilation. As with all simulations, students will derive the most benefit if:

1. Diagrammatic representations are provided
2. The simulation is repeated in multiple contexts
3. The instructor takes the time for an extensive debriefing.

**About the Author**

*Kerry Hull* teaches Physiology, Exercise Physiology, and Anatomy at Bishop’s University, a small liberal arts institution in Southern Quebec. A molecular endocrinologist by training, she has recently transitioned to what she terms the “much more satisfying enterprise” of pedagogical research. She has been attending HAPS conferences since 2008, and is currently the Chair of the *HAPS Educator* committee and the HAPS Educational Research Task Force.

**Literature Cited**


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Avascular Necrosis of The Femoral Head: Associated Anatomical Features and Treatment Options

Sarah Cooper, MEd¹ and Gabriel Burklund²

¹ Department of Biology, Arcadia University, Glenside, PA 19038
² Biology/Pre-Prosthetics, Arcadia University, Glenside, PA 19038

Abstract
Avascular necrosis of the femoral head may lead to the progressive destruction of the acetabulofemoral joint. The etiology of the disease is not well characterized. Risk factors for the disease include trauma, corticosteroid use, alcohol consumption and abnormalities in blood coagulation. The disease is diagnosed using MRI and staging of the disease is done primarily by assessing the size and location of the necrotic lesion. Treatment for younger patients in whom the femoral head is still intact includes core decompression and bone grafting. Total hip arthroplasty is the treatment of choice when the femoral head has collapsed.

Keywords: Avascular necrosis, acetabulofemoral joint, ischemia, femoral head, core decompression, bone grafting, corrective osteotomy, bone growth factors, stem cells, total hip arthroplasty

Introduction
Avascular necrosis or osteonecrosis is a disease characterized by the progressive deterioration of bone at the cellular level due to a disruption in the blood supply to the bone. If the affected bone is located in a joint, joint collapse may be the end result of this bone-destroying process. Avascular necrosis can affect any bone but it is most often found in the bones of the hip, knee, ankle, wrist and shoulder joints. The most characteristic sites for the disease include the femoral head, the neck of the talus and the waist area of the scaphoid. In long bones, avascular necrosis most commonly affects the epiphyseal area of the bone (Zalavras and Lieberman 2014, Moya-Angeler et al. 2015).

Several risk factors have been identified for the disease. People who have been on high doses of corticosteroids, those who regularly consume several alcoholic drinks a day, and those who have suffered traumatic injury to a joint have the greatest risk for developing avascular necrosis. Other risk factors include decompression disease, hypertension, sickle-cell anemia, Gaucher’s disease and radiation for cancer treatment. Twenty to forty percent of cases are idiopathic (Moya-Angeler et al. 2015). Long-term corticosteroid treatment is typically defined as treatment that is ongoing for a period of two to three months with a daily dose of two grams of a cortisosteroid such as prednisolone. For alcohol consumption, the critical dose is the consumption of 320 grams of ethanol per week. This is equivalent to drinking approximately five bottles of wine per week (Arbab and König 2016).

The progression of the avascular necrosis follows a predictable course. When the blood supply to bone is reduced or interrupted, hematopoietic cells in the bone marrow are the most susceptible to the resultant lack of oxygen and nutrients and they die within 12 hours. Osteoblasts, osteoclasts and osteocytes survive for a little longer but these cells usually die within 12 to 48 hours. Adipocytes of the bone marrow eventually die, most within five days of vascular disruption (Kahn 2016). If the affected bone can be re-profused with blood, osteogenesis follows the normal course including the migration of undifferentiated mesenchyme cells from adjacent bone areas into vacated marrow spaces and the movement of macrophages into the area to remove cellular debris. This is followed by the differentiation of mesenchyal cells into osteoblasts or fibroblast cells, which in turn support the formation of a new mineralized framework in the bone.

Avascular necrosis most commonly affects people who are still relatively young. Most patients are men between the ages of 30 and 50. In the United States each year 20,000 to 30,000 people are diagnosed with avascular necrosis. Surgical treatment of these individuals accounts for between 5% and 12% of all total hip arthroplasties (THA) that are performed in the United States each year (Zalavras and Lieberman 2014, Moya-Angeler et al. 2015).

Symptoms
The ischemia that characterizes avascular necrosis may result from a disruption in the blood supply secondary to traumatic bone fracture that impedes blood flow to the femoral artery, the profunda femoris artery, the medial femoral circumflex artery, the lateral femoral circumflex artery and/or the epiphyseal arteries (Turek 1984). The most vulnerable blood supply consists of the vessels that are located on the posterior-superior aspect of the continued on next page
femoral neck, between the greater trochanter and the femoral head (Biswas and Biswas 2004). Other causes of bone ischemia include: compression associated with the infiltration of fat deposits into the bone marrow secondary to the consumption of corticosteroids or alcohol abuse, vasoconstriction of the epiphyseal arteries associated with corticosteroid use, or intravascular occlusion secondary to fat or gas embolization, thrombosis, or aggregations of red blood cells in sickle cell anemia (Zalavras and Lieberman 2014, Moya-Angeler et al. 2015). Thrombosis may be associated with abnormalities in the clotting process or a genetic predisposition to clotting abnormalities. Specifically, a thrombophilic mutation of factor V Leiden is seen more frequently in patients with avascular necrosis (18%) compared to an avascular necrosis-free control group (5%) (Zalavras and Lieberman 2014). Patients with avascular necrosis are also known to have a reduction in mesenchyme cell differentiation leading to the production of osteocytes, as observed in cells derived from the proximal femur (Zalavras and Lieberman 2014).

Avascular necrosis is often asymptomatic in early stages. When symptoms appear, patients commonly describe significant pain in the groin area that is likely to radiate into the knee and the area of the ipsilateral buttocks. Internal rotation of the hip is often painful. Extreme pain associated with internal rotation of the hip may be indicative of the collapse of the femoral head (Moya-Angeler et al. 2015).

**Diagnosis:**

Avascular necrosis is primarily diagnosed by magnetic resonance imaging since MRI is 99% specific and sensitive for diagnosis of the disease. Plain X-ray images often appear normal in the early stages of the disease. In later stages, X-rays may show characteristic sclerotic and cystic bone changes in the femoral head (Zalavras and Lieberman 2014).

A marker known as the crescent sign may be seen on X-ray in the later stages of the disease. The crescent sign is a radiolucent marking that appears as a curved subchondral line along the boundary of the proximal femoral head (Kenzoza and Glimcher 1985). This marker is best observed on X-ray when the patient’s legs are arranged in an abducted position often referred to as a frog-legged position. The crescent sign is related to the progression of the disease where new bone is being laid down over dead trabeculae in the femoral head. In this stage the underlying trabeculae are stressed when the bone is subjected to weight-bearing pressure. The pressure results in microfractures in the trabeculae, which trigger the collapse of bone in the affected region (Kenzoza and Glimcher 1985). The crescent sign is the visible indication of bone collapse in the area affected by avascular necrosis and the resultant breaking away of the overlying articular cartilage.

The course of avascular necrosis is progressive. The disease is staged by several classification systems with no one system accepted as the standard in the field. Each system considers the size and location of the necrotic lesion and the presence of bone marrow edema in the proximal femur. The presence of edema is seen as a distinct risk factor for eventual collapse of the femoral head (Zalavras and Lieberman 2014, Moya-Angeler et al. 2015).

**Treatment**

Treatment for avascular necrosis is complicated by the lack of understanding of the specific pathophysiology of the disease. Non-surgical treatments include pharmacologic agents such as lipid-lowering drugs, anticoagulants, bone growth factors such as bone morphogenic protein, and a variety of vasoactive substances. Clinical studies for pharmacologic treatment of this disease are not abundant and a standard protocol has yet to be devised. Biophysical treatments such as extracorporeal shock waves and pulsed electromagnetic fields have been tried, sometimes with moderate success, but there is limited documentation of their use and efficacy (Zalavras and Lieberman 2014). Surgical treatment for avascular necrosis is of two basic types. There are surgical treatments that attempt to preserve the femoral head and those that favor its removal. Generally, treatments associated with the preservation of the femoral head are favored for younger patients in whom the femoral head has not yet collapsed. Treatments that result in the removal of the femoral head are primarily reserved for older patients and those in whom the femoral head has already collapsed (Zalavras and Lieberman 2014).

Femoral head-preserving treatments include core decompression of the femoral head with or without vascularized or non-vascularized bone grafting, with the concomitant use of stem cells and/or bone morphogenic protein. Total hip replacement, known as total hip arthroplasty (THA), is the surgical treatment of choice when the femoral head has collapsed (Zalavras and Lieberman 2014, Moya-Angeler et al. 2015).

**Core Decompression**

If avascular necrosis is detected early and the head of the femur is still intact, a procedure known as core decompression may be undertaken in an effort to relieve the excess pressure that characteristically builds up in the diseased bone. Excess pressure is associated with pain and poor blood perfusion into the femoral head. In core decompression an 8-mm to 10-mm core is drilled into the bone and removed from the antero-lateral segment of the femoral head, leaving behind a hollow cylindrical channel in the bone. The presence of the channel relieves the hydrostatic pressure in the femoral head. The channel may be filled with a vascularized or non-vascularized bone graft and sometimes it is also filled with stem cells and/or bone morphogenic protein, with the intent of encouraging new bone growth in the necrotic area (Zalavras and Lieberman 2014, Moya-Angeler et al. 2015). If new bone can be coaxed into growing in the decompression channel,
this may stabilize the progression of the necrosis. Bone decompression is often an effective treatment in the early stages of avascular necrosis and it does not interfere with eventual hip arthroplasty if this more invasive procedure becomes necessary later on (Calori et al. 2014).

In the vascularized fibular grafting procedure a fibular graft, often accompanied by autologous stem cells derived from the iliac crest and/or bone morphogenic protein, is placed into the hollowed out core-decompression channel in the femoral head and anchored there using wire or a xenographic bone substitute that functions as a cap over the entrance to the open channel (Calori et al. 2014, Hoskinson et al. 2015). An alternative is to use autogenous bone as a cap for this biologic chamber. The establishment of a biologic chamber has been successfully used to augment core decompression and the combination of bone grafting, accompanied by autologous mesenchymal stem cells (MCSs) and/or bone morphogenic protein, sealed in a biologic chamber, is considered to be an effective treatment for early stage avascular necrosis (Calori et al. 2014, Hoskinson et al. 2015).

Corrective Osteotomy
Corrective osteotomy or rotational osteotomy is a bone-preserving surgical option that is sometimes considered as a means of preventing the collapse of the femoral head when the necrotic lesions of avascular necrosis are relatively small and the femoral head is still intact. In this procedure, the necrotic area of the femoral head is carefully rotated away from an area where it is subjected to weight-bearing pressure and repositioned in a non-weight-bearing area of the hip joint, thereby diverting mechanical stress from the necrotic area to healthy bone (Zalavras and Lieberman 2014). This type of surgery is technically demanding and carries a relatively high rate of associated complications including protrusion at the hip joint and the production of tiny particle debris in the operative site that can lead to particle-induced osteolysis (Arbab and König 2016). The success of corrective osteotomy is related to the size of the necrotic lesion and the location of a sufficient amount of healthy bone that can be aligned with the weight-bearing region of the acetabulum. The chance for a good outcome with this procedure is enhanced when the repositioned femoral head can be aligned with at least one third of the weight-bearing region of the acetabulum (Zalavras and Lieberman 2014). Corrective osteotomy has a significant downside in that it may make total hip arthroplasty a more complex procedure should a THA become necessary as the disease progresses (Arbab and König 2016).

Total Hip Arthroplasty
In total hip arthroplasty (THA) the femoral head and the acetabulum are surgically separated and replaced by a prosthetic devise that is constructed of metal or very durable plastic (Calori et al. 2014, Turek 1984). When the necrotic area of the femoral head is very large or the femoral head has collapsed, a total hip arthroplasty is the only treatment that has proven to be successful in restoring

Free Vascularized Fibular Graft
Vascularized bone grafts to encourage the revascularization and support of the femoral head are most commonly derived from the fibula. When compared to non-vascularized grafts, free vascularized fibular grafts (VFG) increase the likelihood of the ultimate survival of a pre-collapsed femoral head in avascular necrosis (Zalavras and Lieberman 2014, Moya-Angeler et al. 2015). The free vascularized fibular graft procedure requires that the peronal artery and vein of the graft be anastomosed to the ascending branches of the lateral femoral circumflex artery and vein of the recipient (Zalavras and Lieberman 2014). Grafting of this type is considered to be technically demanding since it relies heavily on the techniques of microsurgery. It also typically results in some degree of donor site morbidity in about 20% of patients. The associated morbidity may include a variety of sensory abnormalities, disruption of the flexor hallucis longus muscle and transient or permanent motor weakness in the donor site (Zalavras and Lieberman 2014). The ascending branch of the lateral circumflex femoral artery is the most commonly used recipient vessel for vascularized fibular graft anastomosis. In cases where the ascending branch of the lateral circumflex femoral artery is too small in diameter, too hard to get to, or too short to facilitate an anastomosis, the first perforating branch of the deep femoral artery is considered to be an appropriate alternative vessel since it tends to be an anatomically consistent vessel with respect to its location and diameter (Sur et al. 2015).

Area of bone removed for core decompression
Bone removed with blood vessels from the mid-section of the fibula
Vascularized fibular graft in place

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function to the hip joint and relieving pain. Long-term studies report that the success rate for total hip arthroplasty that is performed on patients with avascular necrosis is similar to the success rate for the general population, in the range of 85% to 90% (Moya-Angeler et al. 2015).

Conclusion
Avascular necrosis of the femoral head is a progressive, potentially debilitating disease of people who are relatively young. The major risk factors include the extended use of corticosteroids, trauma, alcohol abuse and abnormalities in the blood clotting cascade. Without treatment, avascular necrosis typically leads to subchondral fractures of the femoral head in two to three years (Arbab and König 2016). Once these fractures appear there is no dependable joint preserving treatment available to the patient other than total hip arthroplasty. If left untreated, the femoral head will collapse and the hip joint will deteriorate to the point where walking is extremely painful and eventually impossible. In advanced cases of avascular necrosis the over-riding goal is to postpone the destruction of the hip joint and total hip arthroplasty for as long as possible (Arbab and König 2016). In the presence of femoral head collapse, total hip arthroplasty is a single procedure that can reliably relieve the pain and restore function to the acetabulofemoral joint.

About the Authors

Sarah Cooper is Editor-in-Chief of the HAPS Educator. She has taught human anatomy and general biology at Arcadia University since 1981 and she serves as the pre-nursing adviser and coordinator of the interdisciplinary science program.

Gabriel Burklund will graduate from Arcadia University in May 2016 with a degree in biology. At various times he has worked as a lab assistant and as an automotive detailer; experiences that have given him a love of “shop-based” science, and steered him towards the field of prosthesis. Some of his passions include producing and performing music. He is a member of the Arcadia University Guitar Ensemble.

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Studio: 143 North Sylvania Avenue, First Floor, Rockledge, PA 19046
tel: 215.379.2832

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Beer Brewing as a Model for Improving Scientific Literacy in Higher Education

Dale J. Wood, PhD
Department of Chemistry, Bishop’s University, 2600 College Street, Sherbrooke, Quebec, Canada J1M 1Z7.

Abstract
Beer is a subject that most University students are very familiar with. Beer is also the product of a myriad of scientific disciplines acting synergistically to create the world’s most popular beverage. As a result, beer brewing is an excellent mechanism for introducing non-science University students to science. Two courses, The History and Science of Beer and Brewing and an Experiential Learning course in Brewing, are summarized by the author and demonstrated as a means of improving scientific literacy in higher education.

Key words: beer, brewing, history, science, scientific literacy, experiential learning

Introduction
Scientific literacy is an increasingly common goal of institutions of higher education (Salamon 2007). However, the challenge of developing and delivering scientific content in a way that resonates with non-science students remains a significant issue for science educators. A key to engaging non-science students with scientific content is to present it as a critical component of something that is very familiar to them (AAAS 2015). Courses along the lines of “The (Insert Science) of Everyday Life” have become common means of doing this, but the approach can be hit or miss depending on which topics are selected as exemplars. Beer is a large part of the culture of the western world, and its popularity is increasing rapidly as a result of the craft beer revolution; particularly in North America, and particularly among University-aged people (18 – 25 years of age). Beer, on a per volume scale, is the most consumed alcoholic beverage in the world (Sneath 2001) and this consumption is, for good or bad, central to the average university student’s social life. In North America, happily, with the resurrection of the pub environment, beer consumption is moving away from being a common means of inebriation toward being a mechanism for peer bonding and healthy social interaction. More and more university students are becoming “beerophiles” as access to the diversity and complexity of craft beers becomes more the norm.

There are few university communities today that do not have at least one microbrewery or brewpub operating nearby. Tapping (pun intended) into this growing interest and familiarity of the student as a means of engagement with scientific content is a beautiful fit.

In addition to a rich history, beer and brewing are excellent examples of the development of scientific pursuit through the ages, from the pursuit of alchemy through to modern medicine. Many of the most significant scientific discoveries (e.g. Pasteur’s discovery of airborne microorganisms, Sorensson’s development of the pH scale) have been the result of studying beer and brewing. Brewing touches upon several scientific disciplines, including microbiology, metabolism, organic, inorganic, and analytical chemistry, thermodynamics, fluid physics, mechanical and electrical engineering, and, if supporting industries are considered, agriculture and environmental studies. Recipe development is a wonderful model of the scientific method, providing a hands-on and interactive example of the concepts of trial and error with an obvious desired outcome: pleasing the consumer.

What follows is an overview of how beer and brewing has been used by the author to promote scientific literacy and engagement among non-science students through the delivery of a course entitled “The History and Science of Beer and Brewing” and via an Experiential Learning course in Brewing.
Learning opportunity made possible by the establishment of an on-campus academic microbrewery; The Bishop’s Arches Brewery.

**What is beer?**
Beer is the name for a very broad array of alcoholic and non-alcoholic beverages. In general, however, beer is an alcoholic beverage prepared from four primary ingredients: water, malted grain, hops, and yeast. There are two primary classifications of beer, ales and lagers, and these are determined based on the type of yeast used for the fermentation stage of brewing. Ales are produced using *Saccharomyces cerevisiae*; a top fermenting brewer’s yeast whose ideal fermentation temperature is between 12°C and 25°C. Lagers are produced using *Saccharomyces pastorianus* (formerly known as *S. carlsbergensis*); a bottom-fermenting yeast whose ideal fermentation temperature is between 4°C and 15°C. Fermentation time depends primarily on fermentation temperature, so ales tend to take less time to produce than lagers. Within these two categories, there are more than 75 recognized, distinctive beer styles, and literally thousands of recipes have been developed within each style. There are hundreds of yeast strains available within the two general types, and each of these contribute differently to the aromas and flavors of a beer. Beers range in color from pale yellow to black, a character derived from the choice of malts. The choice of type and amount of hops used provides a broad range of bitterness, flavor, and aroma as well. Even the mineral content of the water used to brew the beer has a significant impact on how bitterness, flavor, and aroma are perceived. All of this complexity can be rationalized using science, and so science can be used to improve the art of brewing. In fact, this has been going on since the first beer was brewed at least 12,000 years ago.

**The History of Beer and Brewing**

**Brewing as an Alchemical Pursuit**
Beer has been around ever since human beings began consuming grain as a regular part of their diet. Almost as soon as primitive strains of cereals such as barley and wheat were domesticated, a huge factor in humanity developing from nomadic hunter-gatherer to agriculture based villager, beer brewing became an important aspect of the diet and culture of civilized peoples. The oldest evidence of beer brewing comes from the analysis of clay jars that contained a rice beer dating to 7000 BC in Jiahu, China (McGovern 2015). Thanks to the discovery of a stone tablet covered by cuneiform writing dating back to approximately 1800 BC, we have a very good idea of how beer was brewed in ancient times, and the important role that brewing played in society (Civil 1991). This tablet contains a hymn to Ninkasi, the Sumerian goddess to whom beer and brewing were attributed. The hymn is a detailed description of how the priestesses of the goddess brewed their beer, complete down to the individual steps of the brewing process and the ingredients from which the beer was made. It is clear that the priestesses of Ninkasi used an elaborate system of brewing that must have developed over a long period of time using the concepts of trial and error to refine the process. They learned that the beer was better when the grain was baked into a bread called bappir; a process similar to malting which modifies the grain kernel, making the starches and proteins inside easier to access, break down into sugars and amino acids, and extract them into the water. The pre-fermented beer, called wort, was sweetened with honey and flavored with dates and herbs. Prior to the introduction of hops as a brewing ingredient approximately 1000 years ago, local herbs and fruits were commonly used to flavor beer. This is when things got mystical. Microorganisms, such as yeast and bacteria, which we know today are responsible for fermentation, or the conversion of sugars to alcohol, were unknown prior to the 16th century AD. Into a vat went a sweet liquid; out came an alcoholic beverage that provided a euphoric, and sometimes hallucinogenic, experience when consumed. This mystical transformation, in the absence of any other explanation, was attributed to the gods and thus brewing became controlled by the priests and priestesses that served those gods. It was also the responsibility of these sects to make their beer as good as it could be so as to honor the gods. This was an alchemical pursuit as important to human development as metallurgy.

**Important Scientific Advancements Resulting from the Study of Beer**
Beer itself was an important development in human history. Not only was it important to the culture of early civilizations, it is also a rich, nutrient packed, beverage that was an important staple of the diet of human beings up to the present day. A critical stage in the brewing process is the boiling of the wort; the sugar-rich solution obtained by steeping malt in water. This stage has a number of important effects on the nature of the final product that will be described below, but one of these is the killing off of all of the microorganisms that were present in the water and malt (Bamforth 2009). A big problem arising from the collection of large numbers of human beings and livestock into a small area is the seepage of sewage into the water supply. This carried with it microorganisms that cause deadly diseases. The boiling stage of brewing insures that these microorganisms do not survive into the final product and, as a result, the beer was very often a much healthier alternative than the water. Additionally, beer is rich in vitamins and essential elements that the populace was not necessarily getting in the other parts of their diet. Beer became a beverage that was consumed by all ages at every meal of the day. Overseas colonization relied on beer for the health of the crew and passengers of sailing ships destined for the new world. These journeys could take several months and the nutrients in beer held conditions such as scurvy at

continued on next page
bay. One such ship, the Mayflower, was forced to land at Plymouth Rock rather than its actual destination, Boston, because the ship ran out of beer prior to the end of the voyage (Anonymous 1620).

During the Middle Ages in Europe, brewing knowledge became the domain of monasteries. Beer was the perfect beverage for the monks as it supplemented their otherwise frugal diet. Additionally, monasteries had granted to them the land necessary to grow the grain (barley and wheat), and later hops, required to sustain a brewery. The monks endeavored to refine the brewing process and in so doing learned a great deal about ideal brewing conditions and of the process of fermentation. For example, Bavarian monks, recognizing that beer brewed during the cold months of the year was better and more consistent than beer brewed during the summer and was less prone to spoilage, perfected lagering; the process of cold fermentation and cold storage. So much better was the lagered beer that many years later a Bavarian Duke mandated that beer could only be brewed during the winter and early spring. Today lagers represent the vast majority of the beer brewed worldwide. Although they didn’t know it at the time, the Bavarian monks had applied genetic modification to their brewing yeasts, selecting those yeast cells that were capable of fermenting at low temperature and removing those that could not. Over a period of time, and much cold fermentation, this resulted in the isolation of s. uvarum or lager yeast.

It was also Bavarian monks that were the first to use hops in beer. At the time, beer from that region of central Europe used an herb mixture called Gruit as a flavouring agent in beer. Gruit sale was tightly controlled and only apothecaries could do so. It was heavily taxed and therefore it became expensive to procure. It seems likely that hops was used by the monks as a cheaper alternative for beer brewed for themselves. The monks observed that beer brewed using hops was much more resistant to spoilage, and thus had a much longer shelf life, than beer brewed without it. Although it took some time, the benefit of using hops won out over tradition and it replaced Gruit as the primary means of flavoring beer. So important was hops to brewing, and so lucrative was taxation on this flourishing crop, that in 1516 Bavaria enacted the Reinheitsgebot (Eden 1993) (Purity Law) which mandated that beer could only be made using water, barley, and hops. Yeast was later added when its role in brewing was understood. Bavaria insisted that the adoption of the Reinheitsgebot be a precondition of German unification in 1871. The Reinheitsgebot remained a German law until 1987 when it was repealed due to German brewers needing to use less expensive adjuncts, such as corn syrup, to compete economically with brewers from other nations, such as Belgium, that were already doing so.

Beer was also the driving force or the focus of study of a number of important scientific discoveries over the centuries.

Antoni van Leeuwenhoek (1632 – 1723) was the first to observe yeast cells when he examined a drop of fermenting beer under one of the microscopes that he had made. In a letter to Thomas Gale (1636 – 1702) dated June 14, 1680 Leeuwenhoek describes yeast as an aggregation of globules with each globule being about the size of a red blood cell (about 7 μm) (van Leeuwenhoek 1680). Unfortunately, Leeuwenhoek mistakenly equated the yeast cells that he observed with the starch granules in flour and therefore wrongly surmised that yeast derives from cereal grains and is not a distinct biological organism. The credit for classifying yeast as a microorganism goes to Charles Cagnard-Latour (1777 – 1859) in 1838 (Cagnard-Latour 1837). Microscopy had developed significantly in the intervening 158 years and Cagnard-Latour, studying fermenting beer, was able to observe in real time the growth and proliferation of yeast, thereby proving it is a living organism. Furthermore, he was able to show that yeast is a single-celled organism that reproduces via budding and he argued that because yeast cells were not motile that they must belong to the plant kingdom. He was even able to observed CO₂ bubbles originate from the yeast cells.

The great Louis Pasteur (1822 – 1895) was asked by the father of one of his students, a vintner, to determine why wine soured. Pasteur theorized that the spoilage could be the result of something getting into the wine rather than it being something in the wine itself. To test this, he developed his famous gun cotton experiment, in which he passed air through gun cotton and then dissolved the cotton in a mixture of ether and alcohol. He looked at the insoluble material that settled to the bottom of the flask under a microscope and observed a plethora of single celled organisms of differing morphologies that were consistent with types of bacteria and yeast. This proved that microorganisms are airborne and that their falling into open fermentation vats of beer and wine could result in spoilage. Milk spoilage was also linked to microorganisms. These observations led to Pasteur’s postulation that microorganisms were produced by biogenesis rather than spontaneous generation, which he later proved. The knowledge that microorganisms were responsible for spoilage and that they could be killed upon application of heat led to the development of pasteurization. In 1876, Pasteur published “Etudes sur la Biere”, a detailed account of his studies on the effect of microorganisms on the process of brewing and the quality of beer (Pasteur et al. 1879). At the end of this paper, Pasteur put forward a design for an enclosed fermentation system, which revolutionized the brewing industry by minimizing the chance of airborne organisms infecting the fermenting beer.

In 1883, building upon the work of Pasteur and others, Emil Christian Hansen (1842 - 1909), an employee of Carlsberg Laboratory in Copenhagen, successfully isolated a single cell of lager yeast using techniques that he developed and which are still in use today (Rainieri 2009). Hansen was then continued on next page
Beer Brewing as a Model for Improving Scientific Literacy in Higher Education

The approach to science taken in the History and Science of Beer and Brewing course is to ask the question, “How is beer made?” There seems to be an inherent curiosity in many people to know how things work by knowing how they are put together. This section of the course taps into that curiosity by deconstructing beer into its ingredients (malt, water, hops, and yeast) and then explaining the process, and the underlying science, used to put them together. The science is very rich, pulls from many areas of Chemistry, Biology, and Biochemistry, and could easily overwhelm a student with no scientific background. I have found that a conceptual approach, focusing on what and how rather than why, is a good way of keeping the science in perspective. Very often a student will ask a “why” question, and this creates opportunities to delve into the science a little deeper.

How is Beer Made?

Beer is made from four ingredients: malt, water, hops, and yeast.

Malting

Beer is a beverage that is produced from cereal grains such as barley and wheat. The grain kernel is the seed of the plant. Inside the kernel are the embryo and the endosperm, the former containing the genetic material of the plant and the latter being comprised of starch granules inside protein sacs. The kernel is encased in a very hard husk that protects the interior from the elements. When the embryo becomes sufficiently hydrated by immersion in water, it begins emitting hormones that trigger the production of a series of enzymes (Mallett 2012, Briggs et al. 2012). Proteinases break down the protein walls, producing peptides and amino acids, exposing the starches to amylases, which then begin breaking them down to produce sugars, primarily maltose and glucose. Other enzymes break down the interior wall of the husk, making the kernel friable (easily broken open). This process is called germination. The sugars produced are the energy source for the growing plant and the amino acids provide the building blocks for the plant to produce its own proteins. Brewers, however, are not interested in growing new plants. The brewer wants a grain kernel that is friable, in which most of the proteins have been converted to amino acids, but in which most of the starch remains. It is also critical that the enzymes produced by the embryo survive into the brew house because they will continue their job of producing amino acids and sugars, which the yeast will consume during fermentation. The process of producing this ideal grain kernel is called malting and it is carried out by a specialist called a maltster. The modified kernels are called malt.

Malting is a two-step process (Mallett 2012, Briggs et al. 2012). In Step 1, the grain kernel goes through a series of immersion and aeration phases that cause the seed to germinate (see above). When the maltster sees rootlets emerge from the kernel, it is time to begin Step 2: kilning. Kilning is the process of removing the water from the germinated kernel in such a way as to ensure that the enzymes survive. Typically this is done by passing heated air through a bed of the germinated grain (green malt), beginning with low heat and air flow to remove the majority
Beer Brewing as a Model for Improving Scientific Literacy in Higher Education

of the water, followed by a heat and air flow regimen designed to produce the desired type of malt. Kilning is an energy intensive process. During kilning, a complex series of chemical reactions (Maillard reactions) occur between sugars and amino acids to produce a class of compounds called melanoidins (Mallett 2012, Briggs et al. 2012). These molecules are responsible for the color of the malt, and thus the color of the beer. The higher the heat used in kilning, the darker the malt. Kilning also results in chemical reactions that produce many flavor and aroma compounds that impart characteristic malt character to beer. Since these chemical reactions consume sugars derived from starches, kilning at higher temperature results in a depletion of the starch available to the brewer. To ensure that sufficient sugar is produced in the brew house, pale malts high in starch generally make up the majority of the malt content. Specialty malts are selected to contribute the desired color, flavor, and aroma characteristics to the beer (Mallett 2012, Briggs et al. 2012).

In the Malt and Malting sections of the History and Science of Brewing course, we begin by looking at the Barley farming industry, discussing the following topics: the differences between malting barley and feed barley, 2-row and 6-row barley, pests and disease, and the use of pesticides and herbicides. We then look at the biology of the grain kernel and the germination process, followed by a discussion of the kilning process and the development of color and flavor in malt. Kilning is an energy intensive process owing to the thermodynamic properties of water, so the concept of energy and how it’s produced is an important part of this section (Mallett 2012, Briggs et al. 2012). The scientific topics introduced in this section are listed in Table 1.

**Malt + Water = Mash**

Mash-in is the first step in the brewing process. During mash-in, the malts selected by the brewer, previously milled to crack open the kernels, are combined with hot water to produce a porridge-like mash. When the interior of the malt is exposed to the water, the enzymes generated during germination are reawakened and resume the breaking down of the proteins and starches in the malt, producing peptides and amino acids in the case of proteins, and dextrins and fermentable sugars (e.g. glucose and maltose) in the case of starch (Palmer and Kaminiski 2012, Briggs et al. 2012). Each enzyme has an ideal temperature range in which the reaction rate is optimized, so the mash temperature is controlled to allow sufficient time at these temperatures to produce the highest amounts of fermentable sugars and amino acids as possible. If insufficient time within these ideal ranges is not allocated, then the beer will be sweeter with lower alcohol. If insufficient amounts of amino acids are produced, then yeast may not perform as well as possible, potentially leading to longer fermentation time and the development of off-tastes in the beer (Palmer and Kaminiski 2012, Briggs et al. 2012). Another very important consideration is the mineral content and pH of the water used for mash-in. It has been determined that an ideal pH range for mash-in is 5.2 to 5.6 pH units. Enzymes are pH sensitive, as are many of the chemical reactions that occur during mash-in, and polyphenols, which can complex with proteins in the finished beer to cause hazing and often contribute a medicinal off-taste in high concentrations, are more likely to be extracted from the husks of the grain at higher pH. So, if the water used for brewing is either too acidic or too alkaline, then the pH must be adjusted by adding base or acid to it prior to mash-in (Palmer and Kaminiski 2012, Briggs et al. 2012). The mineral concentration in the water must be sufficient to meet the nutrient needs of the yeast during fermentation, and the mineral profile also has a significant impact on many of the final characters of the beer, such as mouth feel (viscosity) and how bitterness and flavors are perceived by the consumer. It is important that brewers know the mineral profile of the water they use so that they can adjust the mineral content to the style of beer that they wish to produce or, alternatively, select styles that go well with their water. If brewers are tapping a municipal water supply, they may elect to remove chemicals, such as chlorine-containing compounds, that are added to the water during water-treatment. Mash-in generally takes 60-90 minutes to complete, after which the wort (the solution produced by mash-in) must be filtered off of the spent grain (what is left of the grain after mash-in). This filtering process is called lautering (Palmer and Kaminiski 2012, Briggs et al. 2012).

In the Mash-In section of the History and Science of Brewing course, students are introduced to the properties of water, the common minerals that water may contain, and what chemical species (acids and bases) contribute to pH. Minerals that have a significant impact on yeast function and beer character are highlighted and discussed. Students are introduced to the enzymes generated by germination, their optimal temperature ranges, and how they act to break down proteins and starches. These include proteinase, α- and β-amylase, and glycanase. We also look at the nature of polysaccharides and discuss which of them are fermentable by yeast (Palmer and Kaminiski 2012, Briggs et al. 2012). The scientific topics that are introduced during this section are listed in Table 1.

**WortBoiling and Hopping**

Once the wort is filtered, it is brought to a boil. Boiling the wort has a number of direct effects, and it is also used to extract chemical compounds from hops (and / or other flavoring agents) that contribute bitterness, flavor, and aroma to beer (Hieronymynus 2012, Briggs et al. 2012). The direct effects of boiling include killing of microorganism that could contaminate the beer, coagulation and precipitation of proteins that contribute to beer haze and foaming, and some darkening of the beer as a result of Maillard reactions between sugars and amino acids in the wort (Hieronymynus 2012, Briggs et al. 2012).
Hops (Humulus lupulus), or more specifically the hop cone (the flower of the hop plant), contains two classes of chemical compounds: resins and essential oils. The former are responsible for the bitter character of beer, whereas the latter contribute flavor and aroma compounds often described as “hop character”. India Pale Ale is a style of beer that has both high bitterness levels and strong hop character (Hieronymus 2012, Briggs et al. 2012). The resins are comprised of α-acids (humulones: humulone, cohumulone, adhumulone, posthumulone, and prehumulone) and β-acids (lupulones: lupulone, colupulone, and adlupulone). Neither the α-acids nor the β-acids are water soluble and they are not bitter-tasting in their unmodified states. In order to get the desired bitterness, these compounds must be isomerized to produce iso-α-acids and iso-β-acids, a process that also renders them water soluble. When added to boiling wort at a temperature of slightly more than 100°C, it takes approximately 80 – 90 minutes to convert roughly half of the acids to their isomers and this is generally the length of time allocated to the boil. A longer boil would result in higher bitterness levels, but there are a couple of trade-offs that need to be considered. Firstly, increasing boiling time also increases the amount of polyphenols (see Mash-In above) that will be extracted from the hops and secondly, bringing the wort to a boil and holding it there requires a significant expenditure of energy which adds to both cost and environmental footprint (Hieronymus 2012, Briggs et al. 2012). The essential oils in hops are a complex mixture of hundreds of different chemical species that can be classified as monoterpenes, sesquiterpenes, or their oxygenated derivatives (alcohols, ethers, esters, and ketones). These species are non-polar or weakly polar in nature and, as a result, they have low boiling points. Exposure of essential oils to the high temperature of boiling wort causes them to evaporate quickly, and after 90 minutes none remain in the wort. If hop flavor and aroma character is desired it is necessary to add hops either late in the boil (e.g. with 15 minutes or less remaining) or to the beer later in the brewing process. The former is called aroma hopping and the latter is called dry hopping, which is generally done by adding hops to the beer post-fermentation when the alcohol aids in the extraction of the essential oils at lower temperature (Hieronymus 2012, Briggs et al. 2012). In the Boiling and Hopping section of the History and Science of Brewing course, we begin by discussing the hop farming industry (growing methods, harvesting and processing, and pests and disease). This is followed by looking at the morphology of the hop cone, and then the chemical composition of the resins and essential oils. Finally, the chemical reactions that the α- and β-acids undergo during boiling, as well as other chemical aspects of the boil, are discussed (Hieronymus 2012, Briggs et al. 2012). The scientific topics that are introduced during this section are listed in Table 1.

Fermentation by Yeast
Fermentation is the means by which, in the presence of a high concentration of fermentable sugars, yeast produces energy for its own growth and the formation of new yeasts cells. In so doing, ethyl alcohol and carbon dioxide are produced. Fermentation can be carried out by a large number of microorganisms, but beer is produced by the action of only two types of yeast: Saccharomyces cerevisiae for ales and Saccharomyces pastorianus for lagers, collectively known as Brewer’s Yeast. There are some styles of beer that require other fermenting microorganisms such as Brettanomyces (wild yeast) or Lactobacillus (bacteria used in producing yogurt) but this is not the norm (White and Zainasheff 2012, Briggs et al. 2012).

Yeast is a single-celled organism belonging to the kingdom Fungi. It is eukaryotic organism (contains a nucleus and other organelles, including mitochondria) and is a facultative anaerobe, meaning that it can produce energy either by respiration or by fermentation. Respiration is the mechanism of aerobic energy production, and it is 15 times more efficient at producing energy, in the form of molecules of ATP (adenosine triphosphate), than fermentation, the anaerobic mechanism for energy production (White and Zainasheff 2012, Briggs et al. 2012). Most organisms therefore, provided there is sufficient amounts of oxygen, will use respiration to produce energy, but Brewer’s yeast exhibits a phenomenon called the Crabtree effect (named for its discoverer) by which high concentrations of fermentable sugars (e.g. glucose) suppresses respiration and forces the organism to use fermentation instead (White and Zainasheff 2012, Briggs et al. 2012). This is ideal for beer production because wort is very high in fermentable sugars, particularly maltose and glucose, and as a result fermentation begins immediately upon adding the yeast, even in the presence of oxygen. It is only toward the end of fermentation, when the fermentable sugar concentration is low, that yeast exhibits some respiration. This has a significant impact on the flavor of beer as chemicals generated during respiration (pyruvate, citrate, succinate, and others) leak from the yeast cell into the beer and react with other wort components to produce a complex mixture of higher alcohols, ketones, ethers, and esters (White and Zainasheff 2012, Briggs et al. 2012).

The length of time required for fermentation depends on the type of yeast used and the temperature at which fermentation is carried out. Ale yeast prefers temperatures between 12°C and 25°C and fermentation is generally complete within 5 days. Lager yeast prefers temperature between 2°C and 15°C and fermentation can take several weeks, particularly if carried out on the cold side. The fermentation temperature also has a big impact on beer flavor due to the fact that volatile chemicals such as sulfides produced during fermentation stay in the beer at low temperature but evaporate away at higher temperatures. A genuine lager, never allowed to warm, has a distinctively

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sulfurous taste and aroma about it (White and Zainasheff 2012, Briggs et al. 2012).

Another property of Brewer’s yeast is that it flocculates, producing large agglomerations of cells. Ale yeast rises to the surface (top-fermenting) of the fermenting beer when it flocculates whereas lager yeast sinks to the bottom (bottom-fermenting). This is one easy way to differentiate between the two types. It is common practice for brewers to recover the yeast from one batch and use it in the next batch of the same type. Originally, when multi-strain yeasts or wild yeasts were used, this was a practice that resulted in better consistency between batches, but in the modern brewery, where single yeast strains are the norm, this is done to reduce costs. Each time yeast is repitched the number of viable yeast cells, relative to the total mass, decreases so that more and more yeast mass must be added to get effective fermentation. Additionally, mutations in the yeast occur over many generations and therefore the more often the yeast is repitched, the more likely that mutated cells could contribute off-tastes to the beer. General practice is to repitch yeast only a few times before a fresh yeast batch is used (White and Zainasheff 2012, Briggs et al. 2012).

In the yeast section of the History and Science of Beer and Brewing course, students are introduced to the cellular structure of eukaryotes and the role of the cell membrane, nucleus, and mitochondria. The properties of Brewer’s Yeast are discussed and the energy producing mechanisms of respiration and fermentation, and the conditions that support them, are covered. A short discussion of microorganisms that can cause beer spoilage and souring, and cleaning and sanitation protocols used to minimize their presence in the brewery, is also part of this section (White and Zainasheff 2012, Briggs et al. 2012). The scientific topics introduced in this section are listed in Table 1.

After fermentation, the beer is transferred either to a conditioning tank or directly to a keg. The conditioning tank is generally cooled to just above 0°C and time is allowed

Table 1. Scientific topics introduced in the History and Science of Beer and Brewing course.

<table>
<thead>
<tr>
<th>Course Section</th>
<th>Scientific Topics Introduced</th>
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<tr>
<td>Malt and Malting</td>
<td>Agriculture (cereals farming)</td>
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<td>Plant biology (kernel morphology, germination)</td>
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<td>Enzymes</td>
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<td>Starches and proteins</td>
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<td>Maillard reactions</td>
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<td>Thermodynamics</td>
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<td>Mash-In</td>
<td>Water chemistry (Analytical and Inorganic)</td>
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<td>Acid-base chemistry and pH</td>
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<td>Solubility and extraction</td>
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<td>Enzyme kinetics</td>
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<td>Saccharides, peptides, and amino acids</td>
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<td>Wort Boiling and Hopping</td>
<td>Agriculture (hops farming)</td>
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<td>Plant biology (hop cone morphology)</td>
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<td>Isomerization reactions</td>
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<td>Essential oils</td>
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<td>Fermentation</td>
<td>Microbiology (yeast cells)</td>
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<td>Metabolism (respiration and fermentation)</td>
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for particulates and some proteins to settle out of the beer. Clarifying agents may be added to facilitate this process. If additional clarifying is desired then the beer can be filtered before carbonation and packaging in bottle, can, or keg. If the beer is transferred directly from fermenter to keg, it is customary to add an amount of fermentable sugar to the beer before sealing the keg. This induces a secondary fermentation in the keg, which generates carbon dioxide, naturally carbonating the beer. This is called keg or cask conditioning (White and Zainasheff 2012, Briggs et al. 2012).

Post-fermentation conditioning, filtering, and packaging are very important aspects of any brewery, and the underly science is interesting. However, these topics are only very briefly discussed in the History and Science of Beer and Brewing Course and so will not be discussed any further herein.

**Brewing and Experiential Learning**

Science is a practical endeavor. The Scientific Method is the philosophical approach to gathering and evaluating data. Simply put, a scientist develops a theory about something they have observed and then designs an experiment, or many experiments, to test that theory. If the results of the experiment(s) support the theory then the results are disseminated with the recognition that future experiments may disprove it. If the experiment(s) does not support the theory then either the theory or the experiment(s) is flawed and must be reevaluated.

Brewing is an excellent example of the application of the Scientific Method. Brewers (scientists) conceive of a beer (theory), often on the basis of beers that they have tasted themselves (observation), and then they develop a recipe (experiment) that they believe will result in the desired beer. The beer is produced in the brewery (laboratory) and the characteristics of the beer (qualitative and quantitative data) are evaluated to determine if the beer meets the brewer’s expectations. If they do, then the beer goes to market (dissemination). If not then the recipe is changed, based on the new observations, and rerun until the desired outcome is obtained.

Much like in experimental science, serendipity can play a wonderful role in the brewery. Sometimes the beer produced may not be exactly what was expected but exhibits interesting characteristics that end up taking the brewer in a new direction, away from the original concept but toward something equally good or perhaps even better.

Students that complete the History and Science of Beer and Brewing course become eligible to enroll in an experiential learning course that brings them into the Bishop’s Arches Brewery to learn the craft. This brewery is a genuine commercial microbrewery, yet also academic in nature, which operates on the concept that brewing is learned best by promoting variety over quantity. The brewery contains three 50 L brewing set-ups and fourteen 50 L fermenters, allowing multiple teams of students to work simultaneously on their creations and also allowing for multiple recipes to be in development at any given time. Students work in teams of two to four (depending on enrolment) and in the opening few weeks of the semester they are taught how to brew using “go to” recipes. Students are also taught about the commercial aspects of the brewery and each team is made responsible for looking after beer sales one afternoon a week throughout the semester. Students are also involved in planning for events supplied by the brewery.

The experiential learning course is project based. Once they have learned how to brew and get a chance to observe how ingredients work together to produce the final beer, each team must decide upon a beer that they will develop, produce, and market. They do so by envisioning the characteristics of color, flavor, aroma, bitterness, alcohol content, etc. that they want their beer to exhibit and then they research beer styles that closely match with those characteristics. They then formulate a recipe, likely based on one published for that style, and brew it, tweaking it in subsequent brews over the remaining weeks of the semester. Each team will have an opportunity to brew as many as ten beers over the course of the semester, and they will have created a beer that is uniquely their own. Furthermore, they will be able to put their beer on tap and sell it, directly observing the reaction of the consumer to what they have created. Creating their own beer is a very rewarding process and students are very proud of what they have accomplished.

Throughout the semester students maintain a brewer’s log in which all of their recipes are detailed. They are taught to format the log in much the same way as a science student would keep a lab notebook, with a careful record of weights, temperatures, and times associated with each stage of the brewing process, as well as detailed qualitative observations of color, flavor, aroma, etc. Quantitative analysis is beyond the scope of this course. At the end of the semester students prepare a report that contains three elements. The first is a detailed write-up of all of the recipes that they worked on; essentially a transcription of their brewer’s logs. The second is a reflection on the things that they learned from their activities in the brewery. The third is a reflection on how their own field of study might be used in a manner relating to the brewing industry.

**Conclusion**

Together, the History and Science of Beer and Brewing course and the Experiential Learning course provide an exciting way for students to be introduced to a wide array of scientific topics (Table 1) and gain practical experience of science through brewing. A discussion of the rich history of beer and brewing is used as the mechanism for engendering strong interest in learning more about the science of brewing and science in general. The experiential learning course further fixes the concepts learned in the classroom...
Beer Brewing as a Model for Improving Scientific Literacy in Higher Education

Dr. Dale Wood is an Associate Professor in the Department of Chemistry at Bishop’s University. He has been teaching Inorganic and Analytical Chemistry for 15 years and studying the Science of Brewing for almost 20. Five years ago, Dr. Wood began offering a course called “The History and Science of Beer and Brewing” as a means of introducing non-science students to a myriad of scientific subjects. This has grown into the establishment of an academic microbrewery, the Bishop’s Arches Brewery, the first of its kind in Canada.

About the Author

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Believing is Seeing: What should we say about “race” in anatomy education?

Andrew J. Petto, PhD
University of Wisconsin—Milwaukee

Abstract
In 1992, Norman Sauer laid down the essential challenge to studying and teaching about “race” in anatomy education for all its related fields: “If races do not exist, why are forensic anthropologists so good at identifying them?” (Sauer 1992, p.107). Indeed; when teaching about human skeletal variation, we regularly have students apply various techniques for sorting the specimens by sex and age and geographic ancestry. If the variation due to sex is real, why is the variation due to “race” suspect...or worse, invalid? There are two reasons, both of which are fundamental to a proper understanding of the nature of biologic variation within our species (or any other): one is the perennial problem of how words are used and understood by different audiences, and the other is the nature of biologic variation itself.

Key words: Race, human variation, anatomy education

What’s in a name?
As a young EMT, I remember being called out to a remote farm in Vermont. On the way, the dispatcher informed us of the nature of the emergency by telling us that the farmer had “suffered a shock”. We prepared to deal with the aftermath of an electrocution, but arrived to discover that the farmer had experienced what we would have called a “stroke”. Clearly, the parties involved understood the meaning of “shock” quite differently, and in this case the consequences could have been serious.

“A word or phrase that has a specific or precise meaning within a given discipline or field and might have a different meaning in common usage” (http://www.dictionary.com/browse/term-of-art) is known as a “term of art”. And “race” is such a term. Biologists use “race” to mean a set of variations observed in different proportions in a local or regional population than elsewhere in the range of the species. Because the boundaries are quite permeable, however, biologic races do not exist as entirely separate entities and they are often not permanent. Raised in a culture that uses “race” as a term of art with a connotation of fixed and measurable separations among human regional or continental populations, our students may not grasp the distinction when we expect them to apply this same term in a biologically accurate way. As Smay and Armelagos (2000) point out, “race” is tangled up in so many different frames of reference for our students that they easily cross-fertilize biologic and non-biologic meanings and interpretations when they hear the term. This is why anthropologists, in particular, have shied away from using “race” to describe human biologic variation, even though it is the proper term to use in its scientific context (for example, Sauer 1993).

However, biologic variation is real; there are significant, anatomically-and-physiologically important differences among human populations in different parts of the world and in their descendants who live in “immigration nations” like those in the Americas. It is vitally important that we teach about human variation and its role in producing the array of features that we see in human populations all over the world. What we want to avoid is the infusion of meaning into one or a few features of biologic variation (such as skin color) when those meanings are unrelated to the biology that produces the variation.

Just as we see in the substitution of “gender” for “sex” (another example where cultural “terms of art” distort the biologic differences between two important subdivisions of the species), the problem with many “racial” categories is not in their recognition of these observable biologic differences among populations, but their attribution of other, non-biologic features to the individuals whom they assign to these groups. For example, if we observe that humans from different regions have a number of physical features that are correlated with their geographic locations (Huxley 1870; Figure 1), it is legitimate to look for anatomic and physiologic correlates to that collection of associated features.

Fig 1. This early attempt to organize human variation into geographic groups by Thomas Huxley (1870) recognizes many regional subdivisions. Obtained under creative commons licensing from https://commons.wikimedia.org/wiki/File:Huxley_races.png.
However, it is not scientifically justifiable to ascribe characteristics to those populations that are unrelated to these observations—a tradition that unfortunately is historically deep in Western science, especially with respect to nonwestern peoples.

**Blame it on Linnæus**

One of the first scholars in the post-Renaissance era to tackle the organization of life was Carl von Linné, most commonly known in the Western scientific literature as Linnæus. His ordering of life on earth, *Systema Naturae* (Linnæi 1758), remains one of the most well-known and influential frameworks for understanding the diversity of life on earth.

Built on the work of ancient Greek philosophers and further developed by Christian theologians, the *scala naturae* (literally “ladder of life”, but referred to as “Great Chain of Being”) organized the all of creation into a hierarchy from the “lowest” minerals, such as sand and soil, though successively more “perfected” organisms and topped off with the angels and God Himself (Ragan 2009). Bonnet (1781) trimmed this ladder somewhat to exclude supernatural beings, but kept abiotic substances and included the “four elements” of the ancients (Figure 2).

![Bonnet’s Scale of Being of the Natural World](image)

Fig 2. An 18th-century representation of the Scala Naturae from Charles Bonnet (translated and redrawn by the author).

These positions were seen as fixed and immutable; each organism placed according to its “nature” from “base” to “noble”.

Even if modern phylogenetics has left these concepts behind, we still use (or try to adapt) the language and categories of von Linné’s “system” when we organize the biologic relationships among earth’s living things. The problem for understanding human variation in a Linnæan context is that von Linné mixed non-anatomic attributes freely with anatomic features to fill out his hierarchy of human “perfection” in his classification.

Here is what von Linné (Linnæi 1758) wrote about the features of human geographic variants:

<table>
<thead>
<tr>
<th>Homo sapiens</th>
<th>Anatomic Features</th>
<th>Non-anatomic Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>... americanus</td>
<td>Reddish; hair: thick, black, straight; nostrils: wide; chin: minimally bearded;</td>
<td>Honest, Choleric; persistent; cheerful; ruled by custom; body adorned with colored lines</td>
</tr>
<tr>
<td>... europaeus</td>
<td>White; brawny; hair: yellow or golden and abundant; eyes: blue</td>
<td>Sanguine; active; adventurous; body adorned with multicolored clothing; ruled by rites (ceremonies)</td>
</tr>
<tr>
<td>... asiaticus</td>
<td>Sallow, wan; hair: bright black; eyes: dark</td>
<td>Melancholic; arrogant; miserly; body adorned with robes; ruled by opinion</td>
</tr>
<tr>
<td>... afra</td>
<td>Black; hair: twisted; nose: ape-like; skin: smooth; lips: thick; breasts: abundant lactation</td>
<td>Phlegmatic; crafty; careless; lazy; women without shame; ruled by chief; body oiled or greased</td>
</tr>
</tbody>
</table>

We notice at once his tendency to mix physical features with temperamental attributes and a judgment about the dominant or most abundant of the four “humors”. But there are other problems.

For example, the comparison of physical features is superficial and incomplete. Skin and hair colors and other characteristics are provided consistently, but the other physical features are not (compare this to the completeness of the comparisons in the non-anatomic attributes). Second, some of these physical descriptions are patently untrue: all Europeans are not blue-eyed blonds, for example. And other populations have females who lactate abundantly. Clearly, the attributions were clear and complete in von Linné’s mind before gathering the scant biologic data presented here.

This comparison shows that the intellectual history of our approach to the significant differences between human populations is more rooted in cultural attributions than in systematic observations of biologic variation within our species. And the problems we have with “race” today can be traced to those roots: whatever biologic variables we CAN identify, stand as a proxy for the attributes that we ascribe to “others” whom we encounter. European scientists at the time already “knew” and believed in these differences, so “seeing” the associated distinctions among the physical features of the populations was practically unavoidable.

Indeed, Alfred Russel Wallace, a co-discoverer of the role of natural selection in evolutionary change and a keen observer of biologic variation, made these observations in the discussions after Huxley’s (1870) paper was read:

*The great Mongoloid group, for instance, was distinguished by a general gravity of demeanour and concealment of the emotions, by deliberation of speech, and the absence of violent gesticulation, by the rarity of laughter, and by plaintive and melancholy songs. The tribes composing it were pre-eminently apathetic and reserved; and this*
character was exhibited to a high degree in the North-American Indian, and in all the Malay races, and to a somewhat less extent over the whole of the enormous area occupied by the Mongolid type. Strongly contrasted with these were the Negroid group, whose characteristics were vivacity and excitability, strong exhibitions of feeling, loud and rapid speech, boisterous laughter, violent gesticulations, and rude, noisy music. They were preeminently impetuous and demonstrative; and this feature was seen fully developed both in the African Negro and in the widely removed Papuan of New Guinea. This striking correspondence of mental with physical characters strongly supported the view that these two at least were among the best-marked primary divisions of our race. (p. 411)

How many human races are there?

Look at the opening ceremonies at any Olympics. Some countries’ teams seem to epitomize the expected physical features of populations from their part of the world. Other teams seem to have no one physical type that is most common. This is because what makes a biologic “race” is some degree of biologic separation (biologists do not agree on exactly how much) maintained by interactions with local and regional environments, combined with the direction(s) and pattern(s) of interbreeding among populations.

So the answer to the question in the section heading—as with so many questions in biology—is, “It depends.” If we think of populations with fixed, impermeable boundaries in which all the individuals tend toward a certain “type” ... then there are none. If we think of populations that might be partially bounded by geophysical boundaries (mountains, oceans, glaciers, and so on) or separated by great distances so that exchanging genes between them is either difficult or possible in only a few specific ways, then there could be hundreds. It sometimes helps to think of these boundaries as “semipermeable”: gene flow (and its inverse genetic isolation) will be determined by both the selectivity of the boundaries and the external conditions that enhance or inhibit movements across them.

However, some of the differences between human populations are due to general environmental variables that affect all organisms (or at least all mammals) in the region. For example, David Epstein (2013) points out in his book The Sports Gene, that the physique of the African long-distance runners is not simply a matter of genetic endowment in African populations. The relatively longer, leaner physique that makes these runners successful is easily explained by “Allen’s rule” which shows how body shapes and proportions vary according to the heat load in an environment. Longer, leaner bodies are expected where losing heat has a greater survival value and shorter, stouter bodies where conserving heat has greater survival value. This is true not only for humans, but for other mammals, as well. This body type in African populations, therefore, is due to a general phenomenon that is independent of the population (or even the species). It is not a characteristic of a human “race” even though it is commonly associated with populations that live in certain regions and climates. We should also expect similar body types in other regions where there is a comparable heat load, just as we ought to expect the opposite—shorter, stouter physiques—in regions where conserving body heat has a survival value.

We see this in skin color variation, as well. Skin color is a relatively reliable indicator of the amount of solar radiation experienced by ancestral human populations (Chaplin 2004), and so it is most strongly influenced by latitude and by vegetation cover. It is important to note that Chaplin (2004) is mapping the skin color variation in indigenous peoples. An updated map of Chaplin’s (2004) findings can be located here: http://www.understandingrace.org/humvar/skin_02.html; there is also a well illustrated (and captioned) talk on this issue by Nina Jablonski (https://www.ted.com/talks/nina_jablonski_breaks_the_illusion_of_skin_color?language=en). So, skin color does not tell us about “race” per se, it tells us about latitude...mostly.

There are notable exceptions to this trend. Consider the Saami and the Inuit peoples. Both live at high latitudes, mostly above the Arctic Circle (66°34’ N). The Saami have the light pigmentation that we might expect at high latitudes, but the Inuit are much more darkly pigmented. If regulating production of Vitamin D is the driving force behind the skin-color gradient, then the Inuit must acquire this nutrient elsewhere than from solar radiation.

We also find skin pigmentation that is considerably lighter in the Amazon rain forest that we would predict from the equatorial location, but populations living in coastal regions of South America have the deeper pigmentation predicted by their regions’ latitudes. Because Chaplin (2004) is focused on indigenous peoples, we can exclude the potential influence of admixture between indigenous peoples and European colonists or African slaves—and in any case, this would be a much stronger argument for the east coast than for the west coast of South America.

Therefore, the most common ways that we divide people in “races” appear to be driven by external environmental factors that interact with mammalian biology, rather than by large, intrinsic biologic differences among populations living in different parts of the world. And that means that these features could change from generation to generation if descendants grow up under different environmental conditions.

What about genes?

Thanks to the research spurred (eventually) by the pioneering work of Gregor Mendel, we know a lot about how genes affect various anatomic and physiologic features of organisms. We know that the outward appearance of an individual is due to a number of interactions among genes continued on next page
and between genes and the environment. So, we usually presume that differences we see among individuals (or populations) are based on significant differences in their genes. Let’s consider, however, an example or two.

**Tiger Woods and his children.**

Tiger Woods is a good example of how phenotypes can mislead us about genotypes. Based on his family history, Woods’s ancestors came from 4 different continents: Asia, Africa, Europe, and North America. According to that family history, Figure 3 shows his genetic make-up by continent of origin—based on the principle that a child receives, on average, half of his genes from each parent.

**Fig 3.** The relative proportions of genes from ancestors in different continents reported in the ancestry of Tiger Woods.

Despite the fact that Woods would be categorized on sight in almost any US community as primarily “African” in his heritage, his genes tell us that he is more Asian than anything else.

When we take this to the next generation, we see that Woods’s children get half their genes from him (and again, on average their proportions of genes from Asian, African, European, and North American ancestors will be half that of their father’s). But they also get half their genes from their mother, who appears to have only European ancestors (at least in the last few centuries).

Figure 4 shows the genetic make-up of Woods’s children.

**Geographic Ancestry by Continent**

**Tiger Woods’s Children**

<table>
<thead>
<tr>
<th>Continent</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>25.0%</td>
</tr>
<tr>
<td>Africa</td>
<td>6.3%</td>
</tr>
<tr>
<td>Europe</td>
<td>12.5%</td>
</tr>
<tr>
<td>N Am</td>
<td>56.3%</td>
</tr>
</tbody>
</table>

Woods’s children, therefore, on the grounds of the continental ancestry of a majority of their genes would have to be considered European (or “white”). In other words, if “race” is determined by genes, then Woods and his children are difference “races”. This conclusion generally astounds our A&P students.

Furthermore, consider the two children in Figure 5. We show this photo in an in-class exploration called “Who’s an Indian?” Students recognize the differences between them in the physical features that underlie our folk concepts of race. However, these two children are full siblings: they have the same parents. If we used only color criteria and a few superficial facial features, then we might put them in different “races”.

**Fig 5.** Two full siblings showing differences in physical features often used to divide human populations into “races” (skin color, eye color, hair type and color, nose morphology, and so on). Photograph by Andrew Petto.

Believing is Seeing: What should we say about “race” in anatomy education?

continued on next page
The skin color differences in these two children are the result of nothing more than the normal recombination of genes in sexual reproduction. It is, our students should learn, exactly why sex was invented and why so many organisms use it to reproduce—despite its drawbacks: it provides a set of offspring who are slightly different from each other. It produces and maintains biologic variation within the species.

These two examples show the potential errors that students may make in presuming that there is a straightforward genetic component to race: that separate races have vastly different genotypes that are closely related to the observable phenotypes. They are often shocked to learn that this is not the case, as did white supremacist Craig Cobb when his DNA sequencing was revealed on a television show: https://youtu.be/p-XDKio-i4Q.

What does it mean for teaching Anatomy and Physiology?

There are two lessons for those of us who are teaching Anatomy and Physiology and two main strategies to use. First the lessons: (1) While we stress the relationship between structure and function, there is a lot of tolerance for variation in the system; functionality is favored over perfection. (2) We also need to stress that our students understand the meaning and impact of human biologic variation in the context of our their future careers as healthcare providers.

Form and Function

In exploring form and function relationships, or example, consider a recent television ad for Xeljanz® that tells us “arms were made for hugging” (https://www.youtube.com/watch?v=ix3XxbhnuOYU). Arms are certainly used for hugging, but arms are used in a lot of ways. In evolutionary terms, our ancestors used their arms first in general locomotion, then in climbing, and later in throwing. Each one of those uses has an effect on the form and function relationship; if this effect can support an advantage in survival or reproduction, future generations (and future daughter species) will have these morphologic features as a foundation, which they can further modify in new environments.

Hugging is one thing that the structure and function of the arms and their joints allow us to do. More than being careful with language, we also need to help our students appreciate the wide variety of possible uses in an anatomic complex, some of which are essential, and others of which are possible (Bock and von Wahlert 1965). Thus, our arms are not much good at flying, but they can provide a way for us to swim (and to hug).

Exploring biologic variation in health and disease

Second, the importance of human variation especially in the biomedical fields cannot be understated, especially in light of the emergence of “racial medicine” which presumes that we can tailor prevention and treatment to be more effective if we use “race” as a variable in the decision. Consider Burroughs et al. (2002) who lay out the case for the impact of how genetic variation can affect responses to pharmaceuticals. It is indisputable that our genes produce physiologic conditions that affect how we might respond to pharmaceuticals. What is disputable is whether the ways that we categorize people by race or ethnicity is highly correlated to those physiologic differences.

We can help our students explore these presumptions using real-world medical issues. Take, for example, “salt sensitivity” that we see as related to hypertension in people of African descent (though we also see it in other geographic populations as well). One race-based model explaining the relatively higher prevalence of salt sensitivity of people of African descent in North America is the so-called “slavery hypothesis” which states that deprivations on the Middle Passage from west Africa to North America “selected out” those individuals who could not conserve sodium under heat stress and water deprivation. And then later, generations of work under heat stress on plantations reinforced this selective pressure (Grim and Wilson 1993).

This is an intriguing hypothesis. We know that “salt-sensitive” individuals respond to an abundance of dietary salt with a tendency to increase renal resorption of sodium and water (for example, Dunstan et al. 1986). We also know that they have a relatively low level of activity of the renin-angiotensin-aldosterone system (RAAS) in relation to salt intake. The physiologic aspect most relevant to the hypothesis is the tendency to conserve serum sodium even when sodium is abundant—generally an advantageous trait when access to salt is variable or unpredictable (Weder 2007).

The good news is that we can now test the predictions of the “slavery hypothesis” by looking at distributions of alleles related to the RAAS. What we should expect from this hypothesis is that selection for conservation of sodium would result in measurable differences in the frequencies of alleles that we know affect the activity of the enzymes, receptors, and/or hormones related to the RAAS. Figure 6 are the data collected by Rotimi et al. (1996) from populations in Nigeria, Jamaica, and Illinois. The slavery hypothesis would predict the most significant differences in these alleles would occur between populations from Jamaica compared to those in Nigeria; and, of course, that the direction of those changes would be to more salt sensitivity as we proceed westward.

continued on next page
Fig 6. Relative frequencies of the alleles of three genes associated with the RAAS from samples in Nigeria, Jamaica, and Illinois. Data extracted from Rotimi and others (1996). The authors report that ACE I/D polymorphism is associated with different levels of circulating angiotensin converting enzyme; and that two variants of the angiotensin gene (AGT)—M235T and T174M—affect the levels of circulating angiotensin.

Of the three loci related to RAAS examined by Rotimi et al. (1996), only one—M235T—shows a significant shift between Nigeria and Jamaica that could have occurred in the “middle passage” across the Atlantic. The homozygous TT genotype is the variant associated with salt conservation and salt-sensitive hypertension (Rotimi et al. 1996). The frequencies of the homozygous TT genotype in Jamaica and Illinois are about 20% lower than in Nigeria; and the frequencies of the heterozygous TM genotype in Jamaica and Illinois is about double that in Nigeria. This is the only difference among the populations for these genes that was statistically significant. The predictions from the slavery hypothesis would be that the frequency of TT should increase in Afrocaribbean and Afroamerican populations relative to their founder populations in West Africa due to differential survival of individuals with the ability to conserve sodium during the middle passage.

However, Rotimi et al. (1996) estimate that a significant part of the reduction in the homozygous TT genotype in the T235M variant of the AGT (angiotensin) gene is due to European admixture in America, and not to the selective pressure of surviving transport on slave ships across the Atlantic. This inference is strengthened by van den Born and others (2007) who note that this same TT genotype is associated with hypertension in populations of European descent. The TT genotype has a significantly lower frequency in European populations than in African populations, but in the Caribbean, where a significant admixture of these (and other) populations is known to have occurred, the frequency of the TT genotype is actually lower than in Nigeria—and this reduction in the salt-conserving genotype frequency is the opposite of the prediction of the “slavery hypothesis” which would predict an increase in the salt-conserving genotype.

What makes it a “disease”?
None of these should be interpreted to mean that hypertension and salt-sensitivity are not serious health issues in modern societies. Salt is readily available in abundance. However, humans have a number of “thrifty genotypes” that seem to be quite useful under the right environmental conditions and quite harmful in Western society where none or few of those conditions are found. Weder (2007) argues that salt sensitivity in the original African savanna environment of our earliest hominin ancestors would have been quite a useful feature. It was only later migrants who were able to survive well without this feature in their new homes. The lower frequencies of the TT genotype in European populations lowers their risk of hypertension in an environment where salt is abundant. In other words, these genotypes produce essentially the same physiologic results regardless of where our ancestors came from; the difference among populations is in the relative frequencies of the genotypes.

And we find similar outcomes with other genotypes that made the transition to living in Europe more successful: decreased quantities of melanin in the skin and lactase persistence into adulthood, among them. These and other examples that we can document should not surprise us, but Weder (2007) cautions that we need to be careful and responsible in basing clinical decisions on these expectations about the diseases, conditions, and pharmacologic responses of human subjects with particular “ethnic” backgrounds. This is especially true in immigrant nations like ours, where many individuals have a mixture of geographic ancestries.

To take a less life-threatening example, a person who appears obviously to be of European descent has an 80% chance of tolerating lactose as an adult compared to a 20% chance in sub-Saharan Africa or East Asia.

Fig 7. A generalized map of the estimated levels of lactose “intolerance” around the world (estimates are not verified). Some of the distribution of this trait fits with traditional notions of human “races” while others do not. Available from https://commons.wikimedia.org/wiki/Category:Lactose_intolerance#/media/File:Laktoseintoleranz-1.svg and obtained under creative commons licensing.
If we just see light or dark skin and presume the subject’s ability to digest milk, we will be wrong at least one time out of five. The sociocultural assignment of an individual to a racial group does not give us the last word on anatomic and physiologic characteristics of the individuals we include in that group.

What broad categories of human geographic ancestry can do for us is give us a starting point for asking questions. In essence, this is a Bayesian approach (McGrayne 2011) to the pattern of similarities and differences among human populations in form and function: if we know X, then it helps us to estimate Y better. The more Xs we know, the better our estimate for Y becomes; but we can be fooled by only one X. Martinez-Cantarin et al. (2010) make this point about salt sensitivity by looking at other loci that might affect how the genotypes for angiotensin-converting-enzyme perform under different conditions.

So, dark skin color with an African ancestry predicts an 84% chance of having the TT genotype for salt sensitivity if the individual is Nigerian. But, if that person is Jamaican or North American, that probability drops to 68%...with a corresponding rise in the frequency of the less sensitive TM genotype. Furthermore these responses can also be modified by the genotypes at a number of other loci (Martinez-Cantarin et al. 2010). That is to say, the African ancestry has a different meaning in a different context.

**Fuzzy edges**

The final thought here is about drawing boundaries. As I said earlier these boundaries among regional populations are variably permeable. And the result is that there is no such thing as a “pure bred” human (or anything else) entirely free of the genes shared with other geographic variants. Craig Cobb was surprised to hear that as much as 14% of his DNA came from a source in sub-Saharan Africa (see above), though it would not surprise anyone who knows that humans emerged first in Africa and then migrated throughout the world.

The characteristics that we encounter in any population will reflect its evolutionary history, as well as the degree of permeability of the boundaries and the shorter-term responses to local or regional environments. For example, over a period of about 10 years beginning in the early 1980s, my students recorded anthropometric, genetic, and ethnic data for a study of human variability in our classes. My students in Providence RI were made up of a greater proportion of recent immigrants than my students in Madison WI or Calgary Alb. My students in Amherst, MA, and Philadelphia, PA, were intermediate between these.

One trend we noticed was that students were getting bigger as we went west. The difference was small, but statistically significant (about a 0.5-cm increase in head width, for example). Some of this was environmental, but some of it was due to the genetic admixture that comes from longer-term interactions across multiple generations in an immigrant country. For example, when asked to describe ethnicity, we saw that there was positive assortative mating at first with people of the same perceived ethnic background. But later, assortment might take place along shared religious grounds; or shared schooling or employment, so that ethnic distinctions become fuzzier.

One set of data is represented in Figure 8: the range of values in stature among several hundred of these students from across North America. This chart represents a subset of the original data set consisting ONLY of students who reported their ethnic heritage as located only on a single continent.

![Mean Stature by Continental Origin](chart)

**Fig 8.** Stature of North American university students by continent of self-identified ancestry. Only students who reported only a single continental ancestry were included in these data. The solid figures represent the values in the 25th - 75th percentile. The dashed lines represent the minima and maxima for each group.

Figure 8 shows us the ranges of statures in our students for three continental populations. On the left side of the figure are the data from both sexes combined. The solid parts of the figure show the middle 50% of the distribution, and the ellipses show the minima and maxima for the three groups. If we look at the “average” we get a different picture than if we look at the extremes, but in both cases, we should come away with the same general impression: there is a lot of overlap.

We can refine this image more, by extracting the one variable we know has a strong influence on stature: sex. The images in the middle and on the right show that a lot of the differences that we saw in data for sexes combined probably have to do with the relative proportions of females in the three continental populations in our samples. It also turns out that there is more variability in this measure among groups of females than among groups of males. It is also the case that the shortest and the tallest person in the database both self-identify as of European descent.

Using formulae based on a large sample from indigenous populations (Steele and Bramblett 1988), we also found that many of our students fell outside the standard 95%
confidence intervals for the relationship between stature and limb length. More of the errors occurred among students who listed a non-European ancestry, which is another indication of unacknowledged admixture combined with a change in environmental conditions.

Finally, the table below shows what happens even with a small number of individuals when we look for Joe (or Joan) “average” (Petto 2015). These data reflect anthropometric measurements from a selection of 20 students in the data set. The final row is the average of the 20 results for each of the variables.

One thing that students see immediately is that it is impossible to find one person who is “average” on all 20 variables, though some come close on two or three of them. The take-home lesson for our students here is twofold: (1) that the averages give us only a little information, but the range and distribution of the values might help us to understand the patterns of similarities and differences (for example, are their different relationships between groups of shorter and taller people, or males and females?); (2) that no matter how we decide to center our groups, the ranges of variation will overlap considerably and there will usually be a few people who will not fit well into one group or another. Of course, the situation improves when we add more people to the mix, but things get worse when we add more variable.

The point that we try to make here with our students is that the simple genetic traits that we teach about in class—tongue rolling or earlobe attachment—are by-and-large insignificant and trivial. The really interesting and important features of human variation in anatomy and physiology are the complex, polymorphic traits, and these are distributed in a messy and fuzzy way across the categories that we like to set up … even across what seem to be the very clear and distinct boundaries between the sexes.

In such cases—and the earlier example from the study of salt sensitivity is a good example—the pattern of similarities and differences do not stick to our pre-conceived categories. If there is a lesson that I want my students to remember to tell their grandchildren in 50 years, that is it. This lesson is reinforced by the research of Beleza et al. (2013) who show that the genetics of skin-color variation are complex and that the variations in observable skin color have little correlation with specific genotypic differences elsewhere in the genome.

**Take Away**

As these examples have shown, we can find relevant research that explores the real biologic and physiologic variations among human populations. Almost any example will show that these variants—at whatever level of the hierarchy from proteins to overall body proportions—rarely fit well into our sociocultural constructs of what constitutes a human “race”.

However, we can address these issues in our classes by choosing examples that challenge and confront misconceptions based on stereotypes and folk biology. The answer is in using real data in our classes and having students grapple with real problems based on these data.

*If race is a result of genetic differences, then how can Tiger Woods and his kids be different races based on the geographic origin of the majority of their genes?*

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*continued on next page*
If the same genes are responsible for hypertension in Europeans and Africans, why are the rates of this disease different in these populations? Why are Europeans (on average) with hypertension more responsive to salt restriction than Africans?

Ask questions that make your students explore issues and apply data. The process of answering the question is complex, but rewarding (at least that is what my students tell me).

Human biologic variation is real and useful in all biologic disciplines, including anatomy and physiology. Whether we are designing protective gear for female soldiers or solving medical mysteries, knowing how humans vary and what correlated features we may see in individuals with certain geographic origins or with other fundamental sources of human variation can be useful. What we have to avoid—and to teach our students to avoid—is to accept that the first impression is the final word on the anatomic, physiologic, psychological, behavioral (or political) make-up of the individual before us.

The answer to Sauer’s (1992) challenge is straightforward: we can use a limited number of biologic features to identify continental ancestry (otherwise known as “race”) because we have chosen those features that we know reliably reflect that ancestry. Beleza et al. (2013) in their research in populations of mixed ancestry show us how potential errors in this approach can result from presuming that measurable difference in these few traits indicate that some significant part of the remainder of the genome varies as much or even in similar ways.

Previous studies of African-European skin color variation have focused mostly on candidate genes that exhibit large allele frequency differences between ancestral populations, and have led to the view that a small number of loci account for most of the phenotypic variation, in which case skin color should correlate poorly with genome-wide ancestry. Availability of dense genotyping information and new analytical tools allow a more rigorous approach in which the effects of individual loci and genome-wide ancestry can be disentangled and comprehensively investigated.

…Our results indicate that Cape Verdean pigmented variation is the result of variation in a different set of genes from those determining variation within Europe, suggest that long-range regulatory effects help to explain the relationship between skin and eye color, and highlight the potential and the pitfalls of using allele distribution patterns and signatures of selection as indicators of phenotypic differences. (Beleza et al., 2013: e1003372–e1003373)

The features we use to diagnose “race”—either culturally or forensically—are a small subset of the human variation whose distributions do not respect continental boundaries, nor do they strictly correspond to comparable genetic differences in different populations. They are certainly important variables and revealing about the ways in which regional populations relate to each other. However, to focus only on these as a justification for holding on to outdated and unscientific notions of “racial” variation and separateness is to commit one of the cardinal sins of pseudoscience: falling into confirmation bias.

In teaching our students to appreciate human variation as a fundamental concept in its own right, we can help them to see the wonderful, complex, meandering history of our species. It shows us how regional populations are related to—not separate from—each other. And, it provides a meaningful biologic context for the ways in which particular populations do differ from their neighbors.

About the Author

Andrew Petto is senior lecturer in the Departments of Biological Sciences and Kinesiology at the University of Wisconsin, Milwaukee. His doctoral work in bioanthropology focused on comparative functional morphology and primate evolution. After a brief stint teaching in K-12, he began teaching human biology and evolution in higher education in 1981. Since 1989 he has taught Anatomy and Physiology in a variety of programs, including those for nurses, medical technicians, morticians, massage therapists, physical therapists, and dancers. He is the 2015 recipient of the National Association of Biology Teachers’ Excellence in Biology Teaching, Evolution Education Award. His latest book is titled Primer of Anatomy and Physiology, 3/e.
Believing is Seeing: What should we say about “race” in anatomy education?


Determinants of Student Success in Anatomy and Physiology: Do Prerequisite Courses Matter? A Task Force Review 2016

Kerry Hull¹, Samuel Wilson¹, Rachel Hopp², Audra Schaefer³, and Jon Jackson⁴

¹Department of Biology, Bishop's University, Sherbrooke, QC
²Department of Biology, Bellarmine University, Louisville, KY
³Department of Anatomy & Cell Biology, Indiana University School of Medicine, Evansville, IN
⁴Institute for Philosophy in Public Life, University of North Dakota, Grand Forks, ND

Abstract

Successful completion of undergraduate science courses hinges on a variety of factors; among these are the skills and knowledge already held by students and the pedagogical approaches employed by instructors. Researchers have been examining demographic and cognitive factors associated with success in a variety of disciplines, yet there are limited results pertaining specifically to Anatomy and Physiology (A&P) courses. Anatomy and Physiology courses provide a foundation of knowledge that is critical for health professions students, but obtaining adequate mastery of this information proves to be a challenge for many students. Instructors of Anatomy and Physiology courses often observe high failure and withdrawal rates, and gaining a better understanding of the causes behind these attrition rates is necessary to propose adequate solutions. As such, the Educational Research Task Force of the Human Anatomy & Physiology Society has set out to determine if prerequisite courses are related to success in Anatomy and Physiology courses. The HAPS Attrition Survey is being utilized to generate a more thorough understanding of how prerequisite coursework contributes to student success in Anatomy and Physiology courses. Collection and analysis of this data has the potential to fill a large void in current Anatomy and Physiology educational literature.

Key words: anatomy and physiology; pre-requisites; student success; prior knowledge; student attrition

Introduction

The aging North American population will require increasing numbers of well-prepared health care providers. Anatomy and Physiology (A&P) instructors play leading roles in the basic science education of these health care providers, since successful completion of one or more Anatomy and Physiology classes is a strong predictor of success in first year medical-surgical nursing courses (Jeffreys 2007) and eventual completion of the nursing program (Lewis and Lewis 2000). Anatomy and Physiology coursework, however, frequently acts as the chokepoint on a student’s path to a degree or certificate in a healthcare profession (Jenkins and Cho 2012); Anatomy and Physiology courses, in fact, have some of the highest rates of failure and withdrawal of all courses given at the undergraduate level at any given institution (Hopper 2011). Henceforth we will refer to the summed failure and withdrawal rate as the attrition rate. While it is anecdotally accepted that a problem exists, our understanding of the prevalence and underlying causes of this high attrition rate remains tenuous, based, as it is, on a patchwork of limited studies and extrapolations from the general pedagogical literature.

The Human Anatomy and Physiology Society (HAPS) has assembled an Educational Research Task Force to address the issue of attrition in Anatomy and Physiology. In this article, we fulfill the first part of our mandate: to summarize the current state of knowledge regarding factors responsible for the high attrition rate. We focus on one specific factor of particular interest to our members: the relevance of prior knowledge. At the “macro” level of program design, this factor serves as the basis for the second part of our mandate: to systematically analyze the link between prerequisite course requirements and student success in Anatomy and Physiology courses. This article concludes with an overview of the HAPS Attrition Survey, and invites readers to contribute their own data to our research efforts.

1. Attrition Rates: Programs and Courses

A complete understanding of attrition rates in programs involving Anatomy and Physiology coursework is complicated by the fact that these courses are found in both STEM and non-STEM programs. Biomedical sciences are classified as a STEM discipline, alongside such diverse fields as agriculture and natural resources, but health sciences are classified as non-STEM (Chen and Soldner 2013). With that caveat in mind, Table 1 compares program attrition levels in Health Sciences and Biological Sciences in both Bachelor’s programs and Associate degrees. All data is given as the percentage of entering students either switching majors or leaving higher education without obtaining a degree (Chen and Soldner 2013). Attrition rates (as defined by students who either switched majors or left college without completing a degree) are very similar in Biological Sciences continued on next page
and in other STEM disciplines, but Health Science attrition rates (classified as non-STEM) are considerably higher in Bachelor’s degree programs. This difference may reflect the finding of Freeman et al. (2011) and others that nursing, pre-OT and pre-PT students have greater difficulties with Anatomy and Physiology than BSc. (Biology) students. In Associate degree programs the distinctions are even more marked. Attrition due to leaving post-secondary education is much higher for Health Education than for Biological Sciences, but the percentage of students switching majors is considerably lower.

An earlier study by Astin and colleagues (1992) grouped premedical programs under Biological Sciences, and observed that only 36.3% of students who indicated an intention to study in the biological sciences persisted in that decision until their fourth and final year. The remaining students switched to non-science disciplines (42.5%) or to psychology and other social sciences (14.8%).

At the course level, attrition rates (defined as students that withdraw or obtain a grade of D or F) in science and math classes are startlingly high (Belzer et al. 2003, Blanc et al. 1983, Bronstein 2008, Etter et al. 2001). Very limited data paints a similar picture for Anatomy and Physiology. Hopper (2011) reported that 50 of 120 students in Anatomy and Physiology I obtained a passing grade (A, B, or C); thus, the failure rate (D, F) was 58.3%. The withdrawal rate was not provided. While the failure rate was not provided, O’Loughlin (2002) reported a withdrawal rate of 8-13% in a large 200-level Anatomy-only course. Hopp (2009) observed 43.6% attrition rate (D, F, or withdrawal) among first-time takers an Anatomy and Physiology I course over a six-year period. However, a systematic large-scale analysis of attrition rates in Anatomy and Physiology awaits the data obtained from the HAPS Attrition Survey, discussed further below.

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*Data taken from Chen and Soldner (2013). All data is in % of students entering the field.*

2. Non-Controllable Factors Involved in Student Attrition

Investigators have identified a number of non-controllable factors that must be taken into account in any systematic evaluation of student success. Variables recurrent in the literature include gender, socioeconomic status, linguistic status with relation to the program of study, and minority status (Gilchrist and Rector 2007). For instance, higher socioeconomic status positively correlates with student success (Astin and Astin 1992). This relationship appears to reflect secondary school preparedness, parental education level, and parental aspirations (Chen and Soldner 2013, Gilchrist and Rector 2007). Students of European and Asian descent have the most success in postsecondary education (Astin and Astin 1992, Chen and Soldner 2013, Titus 2004). This is supported by additional studies that have documented minority students being at a greater risk for struggling (Attewell et al. 2011, Schutte 2016, Yates and James 2006). It was previously observed that men were more likely to persist in their postsecondary education (Astin and Astin 1992). However, the opposite has been observed with women being more likely to persist in their postsecondary educational programs (Chen and Soldner 2013).

Characteristics of the institution are also highly relevant. Students in four-year bachelor’s programs, for instance, have increased persistence (defined as the percentage of students entering STEM programs that remain in STEM fields throughout their college career) versus two-year associate’s programs (Chen and Soldner 2013). The increased attrition in two-year colleges reflects the distinct demographics of these two institution types, but may also reflect poorness-of-fit between a student and the chosen institution. Students who attend institutions that are below their academic ability have decreased persistence (Attewell et al. 2011). An additional issue is academic aid and affordability, since the costs associated with attending a post-secondary institution have

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*Data taken from Chen and Soldner (2013). All data is in % of students entering the field.*

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3. Why Is Anatomy and Physiology Coursework So Difficult?

Our experience as educators, and a quick survey of health student websites, highlight that students find Anatomy and Physiology coursework incredibly difficult. Students describe it as “taking over my life” and say that they have “never worked so hard” in any other course. Michael (2007) and Harris et al. (2004), identify numerous factors rendering Anatomy and Physiology coursework difficult. These factors include: extra-classroom factors (discussed above), how instructors teach, what prior knowledge students bring to the classroom, and the nature of the discipline. Another issue working against anatomy & physiology is the fact that laboratory components featuring dissection of cats or fetal pigs are somehow deemed “traditional”, and fall victim to curricular reform without anyone taking note of the active, self-directed learning that underlies such laboratory coursework (Turney 2007).

3.1. How Instructors Teach

The mode of instruction is highly relevant to student success and many studies show that incorporating at least some active learning techniques and taking a learner-centered approach promote better learning (Lunsford and Herzog 1997, Michael 2006, Minhas et al. 2012, O’Loughlin 2002) and greater student engagement (Hopper 2016) without adversely affecting knowledge levels (Prince et al. 2003). Indeed, the landmark meta-analysis by Freeman et al. (2014) went as far as describing the inclusion of a lecture-only control group in pedagogical studies of active learning as unethical. Halpern and Hakel (2002) conclude, “It would be difficult to design an educational model that is more at odds with current research on human cognition than the one that is used in most colleges and universities”. We refer readers to the excellent review of active learning published by Joel Michael (Michael 2006) for more details about the cognitive theory and experimental studies supporting the positive impact of active learning techniques on student success. McVicar et al. (2014), however, advises caution when reviewing curriculum intervention studies, since they frequently rely on student perception data rather than objective improvements in student performance.

The characteristics of the instructor may also be relevant and a phenomenon known as the “chilly climate hypothesis” has been postulated as a rationale for the high attrition rate in STEM fields (Daempfle 2003). Students leaving STEM disciplines described the classroom as high for: cold vs. warm, elitist vs. democratic, aloof vs. open, and rejecting vs. supporting. Furthermore, defecting students described members of the STEM faculty as: unapproachable, cold, unavailable, aloof, indifferent, and intimidating (Daempfle 2003). Many students in STEM fields complained of the faculty’s preoccupation with research at the detriment of interaction time with students (Daempfle 2003).

3.2. What Students Bring: Skills and Knowledge

Cognitive theory reminds us “all learning is relearning”. The amount and quality of knowledge and skills students bring to Anatomy and Physiology strongly influence their ability to master the new material (Dochy et al. 2002). Some aspects of prior knowledge, such as English and mathematical fluency and cognitive study skills, are common to all disciplines, while aspects such as visual skills and chemistry knowledge are more specific to anatomy and physiology. A key task for Anatomy and Physiology instructors is to help students successfully piece together new information with pre-existing knowledge in a meaningful way to generate a deeper understanding of the material (Branford et al. 1999). Anatomy and Physiology provides a core of knowledge that can improve students’ understanding of what they do and why they do it in a clinical setting (Branford et al. 1999).

3.2.1. Basic Skills and Remediation

Anatomy and Physiology coursework requires both strong math skills to master physiology concepts and strong reading skills in order to master the large volume of information. One potential predictor of Anatomy and Physiology success for high-risk students may thus be the completion of remedial coursework. A growing number of incoming college students are requiring remedial, or developmental, coursework in reading, writing and/ or mathematics to bring these students’ skills to up to a college-level (Boatman 2010). Placement in such courses is typically based on standardized test scores and/or placement exams (Aud et al. 2013, Boatman and Long 2010). Remedial courses may be for credit but rarely count towards degree...
requirements, thus adding to the cost and time required to obtain a degree. Remedial courses may actually be detrimental to relatively high-achieving students that still “place” into remedial courses. Boatman (2010) observed negative effects of students on the edge of requiring remediation. These students completed fewer credits and were less likely to get their degree than students who did not do the remedial course. Weaker students, however, showed a much stronger benefit. While only approximately 25 percent of students in remedial programs successfully complete remedial courses (Bahr 2010, Bailey et al. 2010). Bahr (2010) found that, students who obtained college-level expertise in mathematics and English via remediation fared similarly to students who entered post-secondary education with similar expertise levels.

Remedial courses are particularly relevant to two-year institutions. In 2003-2004, 64% of students at public two-year colleges required remediation in math, English, and/or reading (Bahr 2008, Bahr 2010, Bailey et al. 2010, Radford et al. 2012). Radford (2012) also summarizes some novel alternatives to traditional remedial courses, such as summer bridge programs, integrating instruction into college-level courses, on-line or in-person modular courses, and also highlights strategies that high schools can use to better prepare their students and thus reduce the need for remediation.

3.2.2: Cognitive Skills

Even in students with adequate entering reading and mathematical skills may benefit from explicit training in cognitive skills. Hopper (2011), for instance, developed a co-requisite supplement course for Anatomy and Physiology students that addressed topics such as higher level problem solving, communication and identifying and using resources. The co-requisite was mandatory for repeaters and optional to all other students. Those enrolled in the course showed lower attrition levels (i.e. attained a grade of C or higher) than those that did not. Schutte (2013) investigated the impact of an optional 1-credit study skills co-requisite for students enrolled in a 200-level anatomy course. Importantly, skills were discussed in the context of the material currently being covered in the anatomy course. Students reported that the study skills co-requisite resulted in improved time management, increased confidence tackling course material, and improved awareness about how to best learn anatomy (Schutte 2013).

Winston et al. (2010) observed a similar result in a medical student cohort; the passing rate of repeaters increased from 58% to 91% once they required a cognitive skills course. Enhancing cognitive skills may be particularly relevant to the transfer of prerequisite knowledge. Supplemental instruction in gross anatomy for medical students resulted in improved student learning, as demonstrated by laboratory practical performance (Forester et al. 2004). Medical physiology repeaters that took a co-requisite course targeting self-monitoring cognitive skills showed a greater improvement in test scores than non-repeaters (Garrett et al. 2007). In a peer-developed supplemental program at another medical school, pre- and post-session quiz scores revealed significant improvements after each session. Student and tutor perceptions of the program showed it to be a worthwhile endeavor for students in either role (Hurley et al. 2003).

Cook et al. (2013) investigated the impact of a one-hour lecture on effective study skills on course grades in a general chemistry course. The average grade of participants was one full grade level above that of students who did not participate. While the authors did not observe any difference between participants and non-participants in terms of important variables such as incoming GPA, they did not measure student motivation, an important determinant of student success (Mega et al. 2014, Schutte 2016). This result may thus, in part, reflect the increased motivation of students who chose to participate in the study skills lecture. Nevertheless, it highlights the potential impact of prerequisite coursework and/or corequisite cognitive skills training.

Often supplemental courses that are helping to improve students’ cognitive skills will address, directly or indirectly, various issues that help improve students’ awareness of how they learn best. This awareness of the learning process is a component of metacognition, which refers to an individual’s knowledge of cognition and regulation of their personal cognitive processes (Bransford et al. 1999, Flavell 1981, Veenman et al. 2006). Students with stronger metacognitive skills often perform better in undergraduate coursework than their counterparts with less developed metacognitive skills (Garrett et al. 2007, Lindner and Harris 1992). Students should be taught to become better regulators of their learning, which can help them greatly in courses with unfamiliar content. Rickey (2000) observed a graduate student with ample content knowledge, but poor metacognition, struggle to solve a problem, while undergraduate students who had strong metacognition but lacked the content knowledge of the graduate student were able to solve the same problem.

3.2.3: Subject-specific Knowledge

Successful mastery of physiology topics requires at least a superficial understanding of foundational topics in chemistry, physics, and cell biology (Michael 2007). While prerequisite courses in these subjects are not universally required, they may help prevent attrition. Beeber and Biermann (2007), for instance, developed a Foundations course to introduce students to the basic cellular biology, laboratory, and biomedical science competencies relevant to Anatomy and Physiology. Students who took the course had lower fail and withdrawal/incomplete rates than those who did not. Students who had taken a previous General Biology course fared even better (Beeber and Biermann 2007), but this result may reflect the higher motivation and background of students who choose to take a course designed for science students. While student performance was not measured, continued on next page
Dawson (2005) reported that 57% of students who had taken a prerequisite General Biology or Foundations course felt that they were well-prepared for their Anatomy and Physiology course.

Hopp (2009) examined the success rate in first-time Anatomy and Physiology students with varying science backgrounds. Students who had successfully completed a college-level science course (Biology, Chemistry, or Physics) fared significantly better (average grade of C) than those who had not (average grade of D). A similar, highly significant trend was observed in students with a previous college chemistry course (average grade of C) compared with those without (average grade of D). This study did not, in itself, indicate causality, since students who have taken a prerequisite science course may simply represent a stronger cohort. However, when these data were used by student advisors to encourage students to take a prerequisite science course before attempting Anatomy and Physiology, the positive correlation between prerequisite courses and Anatomy and Physiology grades remained significant. Thus, for us as Anatomy and Physiology instructors, encouraging students to take a science prerequisite prior to taking Anatomy and Physiology would be a wise thing to do. Taking a prerequisite science course appears to positively correlate with success in Anatomy and Physiology. This finding agrees with another study showing college-level chemistry as a predictor for success in Anatomy and Physiology I (Holmgren and Schoondyke 1991). Indeed, a major recommendation stemming from the meta-analysis of McVicar et al. (2015) was the inclusion of science courses in the admissions criteria for nursing school.

Similarly, by establishing a basic framework of the necessary terminology, undergraduate Anatomy and Physiology coursework may prepare students for professional level studies. Miller et al. (2002) observed that medical students who had taken a previous anatomy and/or physiology course adjusted more easily to the rigors of the medical curriculum. These students also appeared to be more efficient at applying anatomy and physiology concepts to clinical situations.

Hailikari et al. (2008) investigated relevance of prior knowledge in a pharmaceutical chemistry program. Students benefited most when courses were designed as a continuum. Moreover, students who were better able to declare their knowledge at the beginning of the course were more likely to succeed (Hailikari et al. 2008), highlighting the importance of supporting the transfer of knowledge from the prerequisite course to the Anatomy and Physiology course. Rovick et al. (1999) noted that knowledge transfer was particularly problematic when students were asked to apply the information.

3.3. The Nature of the Discipline

By their nature, anatomy and physiology are challenging disciplines. Students need to master a huge volume of technical terms before they can even begin to develop conceptual mastery. As discussed above, they require instructors who are engaged and competent as well as students with strong basic study skills, cognitive skills, and subject-specific knowledge. While these issues have obvious implications for course design, they also need to inform program design, since the positive impact of a prerequisite course can reflect enhanced cognitive skills and/or motivation as well as increased conceptual knowledge (Hopp 2009).

An important issue is WHEN students take these difficult courses. Schutte (Schutte 2016) suggests that students might be better off postponing anatomy to later in their program. It is anticipated that the results of the HAPS Survey will provide insights into this issue. The debate is not confined to undergraduate health sciences anatomy. Medical curricula are experiencing similar conflicts regarding how, when, and how much anatomy to teach to medical students (Turney 2007). The amount of anatomical knowledge needed to be an effective medical practitioner is far greater than what can be effectively taught (or learned) in a typical first-year course, making it both impractical to try and teach it all at once, and imperative to incorporate anatomy into later courses of the curriculum.

4. The HAPS Attrition Survey

Despite the importance of Anatomy and Physiology courses to student success in the health sciences, we still know very little about the prevalence and impact of prerequisite and co-requisite requirements for Anatomy and Physiology courses. Under the leadership of Rachel Hopp (2009), HAPS administered a short survey in 2006 regarding this issue. Based on data from 161 respondents, the survey observed a statistically relevant relationship between a college-level chemistry or biology prerequisite course and student pass rates in anatomy and/or physiology courses. The HAPS Educational Task Force has developed a Student Attrition Survey to expand upon this early work by systematically surveying instructors and administrators about their use of prerequisites and the overall performance of their students. The study will also investigate other factors such class size, course level, student population, and classroom methodology (lecture vs. active) that are important determinants of student success in their own right and may modify the relationship between prerequisite courses and student outcomes. The survey includes questions about the instructor (terminal degree, academic field, years of experience), the courses they teach (credit hours, prerequisites, mode of instruction), and the type of institution (e.g. 2-year, 4-year, or graduate/professional). For each Anatomy and Physiology class taught during the reporting period, the respondent will be asked to provide the percentage of students in each age bracket, program, and grade category (A, B, C, DFW).

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As scientists we should be making evidence-based decisions in education as in the laboratory; yet, instructors and administrators lack the relevant data to optimize program design and course design. On behalf of the members of the Educational Task Force, we encourage all readers to take a few minutes to contribute their data to the project. Our preliminary power analysis suggests that we need a minimum of 220 respondents, so we are counting on your enthusiastic participation. The survey can be found at: [http://survey.ubishops.ca/fs/index.php/742277/lang-en](http://survey.ubishops.ca/fs/index.php/742277/lang-en). Feel free to contact the survey authors at jcksn@mac.com or khull@ubishops.ca.

**References**


**About the Authors**

**Kerry Hull, Ph.D.** is a Professor in the Department of Biology at Bishop’s University in Sherbrooke, Quebec. She teaches anatomy, physiology, advanced physiology, and exercise physiology.

**Samuel Wilson** is graduating with a BSc Honours (Biology, Health Science) from Bishop’s University. He also works as Kerry Hull’s Undergraduate Research Assistant.

**Rachel Hopp** is the HAPS Southern Regional Director. She has been teaching undergraduate biology courses for 17 years.

**Audra Schaefer, Ph.D.** is an Assistant Professor of Anatomy and Cell Biology at Indiana University School of Medicine in Evansville, Indiana. She teaches medical histology and neuroscience, and she conducts educational research with interests in remediation and metacognition.

**Jon Jackson** has taught anatomy and physiology and the history of science for the past twenty years. He is the Western Regional Director of HAPS and a Fellow in the History and Philosophy of Science at the Institute for Philosophy in Public Life.


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Gross Anatomy for Teacher Education (GATE): Educating the Anatomy Educator

Austin A. Doss¹ and William S. Brooks²*

¹University of Alabama School of Medicine, Birmingham, AL, adoss@uab.edu
²Department of Cell, Developmental and Integrative Biology, University of Alabama at Birmingham, Birmingham, AL, wbrooks@uab.edu

*Correspondence to: Dr. William S. Brooks, Department of Cell, Developmental and Integrative Biology, University of Alabama at Birmingham, 1670 University Blvd. Volker Hall 228, Birmingham, AL 35294-0019. USA. Email: wbrooks@uab.edu

Abstract

Qualified anatomy educators are currently in short supply across the United States. As a means of contributing to the training of current and future anatomists, the University of Alabama at Birmingham has designed an anatomy mini-course known as Gross Anatomy for Teacher Education (GATE) the goal of which is to enhance the educational effectiveness of current and future anatomy instructors. Attendees of the first two years of GATE have included anatomy educators from secondary and post-secondary institutions as well as trainees in the biomedical sciences. The GATE mini-course cycles through the four major anatomical regions in a four-year rotation: trunk, back/upper limb, lower limb, and head/neck. Data collected from the first two years of the course have demonstrated much enthusiasm for the program and an improvement in short-term knowledge outcomes. This workshop demonstrates one way in which universities can contribute to the professional development of anatomy instructors throughout the country.

Key words: professional development, anatomy education, adult education

Introduction

The future of gross anatomy education remains uncertain as colleges and universities across the country are dealing with an apparent shortage of qualified gross anatomy instructors. Most of the literature supporting this has been focused on medical education (Carmichael et al. 2005, Holden 2003, McCuskey 2005, Santana 2003, Yammine 2014), but it can be assumed that this shortage extends well beyond our nation’s medical and dental schools. Gross anatomy is a foundational course for many graduate health science disciplines including but not limited to physical therapy, occupational therapy, physician assistant studies, and optometry. Furthermore, with an ever increasing number of students entering health care fields straight out of college such as nursing, radiology technician, and dental hygiene the need for well-trained anatomy instructors in our nation’s undergraduate programs continues to be of utmost importance as well.

The underlying cause of this shortage of anatomy instructors is well documented (Carmichael et al. 2005, Hildebrandt 2010, McCuskey 2005, Rizzolo and Drake 2008). Changes in graduate education during the latter part of the twentieth century with an increased focus on the cellular and molecular levels of biological organization have largely removed gross anatomy training from biomedical Ph.D. programs. So, now only a few graduate programs are producing new Ph.D.’s with formal training in gross anatomy while many of the nation’s classically trained anatomists are reaching retirement. The shortage is only exacerbated by the fact that the number of anatomy instructors needed across the country continues to rise as the number of graduate and undergraduate health science programs also increases. At the undergraduate level, anatomy is typically taught as either a one-semester, stand-alone course or as part of two-semester sequence known as Anatomy and Physiology I and II (A&P I and II). In each case students typically learn anatomy through some combination of images, models, virtual dissections, and small animal dissections. Due to a dearth of graduate trained anatomy instructors, many of the educators teaching these college courses have only had undergraduate anatomy training, while it’s possible that others lack exposure and experience in human anatomy altogether.

There is hope that the current shortage is reversible. New and innovative programs have been established at some institutions to counteract the problem. These programs have included anatomy-focused Ph.D. programs (Albertine 2008, Brokaw and O’Loughlin 2015) and specialized postdoctoral training (Bader et al. 2010, Fraher and Evans 2009). In addition, Northern Illinois University has developed an outreach program geared towards high-school teachers and students (Hubbard et al. 2005), and the Indiana University School of Medicine-Northwest offers an annual cadaveric anatomy mini-course open to a wide array of professionals (Talarico 2010).

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In an effort to contribute to the training of anatomists in innovative ways, the University of Alabama at Birmingham began its own unique program known as Gross Anatomy for Teacher Education (GATE) in 2014. While it is not the first gross anatomy mini-course to be offered, GATE is unique in its mission to provide anatomical instruction and professional development to high school anatomy teachers and anatomy instructors at two- and four-year colleges and universities. In this article, we describe the GATE mini-course and provide data on the success of the workshop in its first two years.

COURSE DESCRIPTION
The Gross Anatomy for Teacher Education mini-course was held over four days in 2014 and three days in 2015 at the University of Alabama at Birmingham School of Medicine’s lecture and gross anatomy laboratory facilities. The course objectives were to: (1) identify the gross contents and organization of the general regions of the human body and (2) relate the study of gross anatomy to common medical illnesses that may be of interest to future health professionals. GATE consisted of regional anatomy lectures in the mornings and cadaveric dissections in the afternoons. Figure 1 illustrates the 2015 GATE schedule. Three UAB anatomists delivered all lectures and facilitated the laboratory dissections. Gross dissections were conducted at a ratio of 4 attendees to each cadaver. In 2014, the mini-course covered anatomy of the thorax, abdomen, and pelvis. The 2015 mini-course dealt with anatomy of the back and upper limb. Plans are in place to cover anatomy of the lower limb in 2016 and head and neck anatomy in 2017. Subsequently, we plan to repeat this four-year rotation so that attendees can be exposed to the entire human body with four years of attendance.

Lectures were similar to those given to medical students and students of other graduate health science programs. One of our goals was to simulate what a medical school anatomy lecture would be like so that those college and university faculty in attendance would be able to tell their students what to expect at the next level of education. Throughout the mini-courses, we emphasized clinical correlates and strategies for teaching anatomy such as mnemonic devices and methods of organizing content for effective delivery and assimilation. The laboratory component of GATE included complete cadaveric dissection performed by the participants. In addition, we provided time for attendees to use ultrasound devices. Some of the attendees even recorded video scans of their own heart to bring back and show their students. In 2014, we also spent one half day teaching attendees about team-based learning (TBL) and how we incorporate it into graduate anatomy education.

GATE PARTICIPANTS
Attendees were able to register for the mini-course as a professional development workshop (registration fee of $450) or enroll in a two-credit-hour graduate course offered by the Department of Cell, Developmental, and Integrative Biology at UAB. Attendees from both registration options were afforded the same opportunities to attend lectures and participate in laboratory dissections. A certificate of completion was presented to those who registered for the professional development option. For those enrolling in the graduate course, an additional requirement was placed upon them to develop a novel anatomy teaching resource that was submitted for evaluation by course faculty. The resources submitted have included team-based learning (TBL) modules, pre-recorded lectures, and laboratory activity instructor guides.

The 2014 GATE mini-course was advertised through e-mail to all public colleges and universities in the state of Alabama and all public high schools in Jefferson County and surrounding counties in the fall of 2013. The mini-course was also advertised to Ph.D. students and postdoctoral fellows in the UAB Graduate Biomedical Sciences program and School of Health Professions. The first-annual GATE mini-course in 2014 was attended by 29 participants, and the 2015 mini-course was attended by 33 participants (Table 1). In the first two years, mini-course attendees representing the states of Alabama, Mississippi, Tennessee, Kentucky, and California were in attendance. The largest group of attendees has come from state community colleges. Attendees were responsible for providing their own lodging during the mini-course. Many of those from outside of the greater Birmingham area stayed at a hotel within walking distance of the mini-course.

2015 GATE Schedule

<table>
<thead>
<tr>
<th>Day 1</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>8:00-8:30</td>
<td>Registration and Breakfast</td>
<td></td>
</tr>
<tr>
<td>8:30-12:00</td>
<td>Anatomy: Back, Spine, and Shoulder</td>
<td></td>
</tr>
<tr>
<td>12:00-1:00</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>1:00-4:30</td>
<td>Dissection</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00-8:30</td>
<td>Breakfast</td>
<td></td>
</tr>
<tr>
<td>8:30-11:30</td>
<td>Anatomy: Pectoral Region, Axilla, Anterior Arm/Forearm</td>
<td></td>
</tr>
<tr>
<td>11:30-12:30</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>12:30-4:30</td>
<td>Dissection</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 3</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00-8:30</td>
<td>Breakfast</td>
<td></td>
</tr>
<tr>
<td>8:30-11:30</td>
<td>Posterior Arm/Forearm, Wrist, Hand</td>
<td></td>
</tr>
<tr>
<td>11:30-12:30</td>
<td>Lunch</td>
<td></td>
</tr>
<tr>
<td>12:30-4:30</td>
<td>Dissection</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Schedule of the 2015 Gross Anatomy for Teacher Education mini-course. Attendees sat through clinical anatomy lectures each morning and cadaveric dissections in the afternoons. Breakfast and lunch were provided each day.
### Table 1: Attendees of the 2014 and 2015 GATE Mini-course

<table>
<thead>
<tr>
<th>Attendee Type</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graduate Student</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>Postdoctoral Fellow</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Community College Faculty</td>
<td>9</td>
<td>21</td>
</tr>
<tr>
<td>University Faculty</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>High School Faculty</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>29</td>
<td>33</td>
</tr>
</tbody>
</table>

Since high school teachers are often required to pay for professional development activities out-of-pocket, we provided scholarships specifically for high school teachers to attend the GATE mini-course. In 2014, the Department of Cell, Developmental, and Integrative Biology covered one half of the registration cost for three high school teachers. In 2015 an educational outreach grant was obtained from the American Association of Anatomists. This grant funded the full registration cost and lodging for three high school teachers.

### RESULTS FROM FIRST TWO YEARS

The efficacy of the GATE mini-course was evaluated through the administration of pre- and post-test assessments and through post-course evaluations. This study was granted exempt status by the UAB Institutional Review Board (Protocol E140305001), and informed consent was obtained from all participants. At the beginning of each course, a 10-question, multiple choice assessment was administered that included questions on clinical anatomy knowledge related to the region that would be studied during the mini-course. Upon the course completion, attendees completed the same 10-question assessment. A representative group of items from the 2015 assessment is shown in Table 2.

Mean post-test scores were significantly higher than pre-test scores (P<0.001), almost doubling each year (Figure 2). A paired Student’s t-test was used for statistical analysis. The limitation of this analysis was that the post-test was separated by the pre-test by only 2 days; therefore, attendees were likely to remember assessment items.

Attendees were asked to complete a post-course survey including a series of Likert scale items and open-ended comments. Mean responses compiled from both years are shown in Table 3 and Table 4. General comments from course participants on the open-ended section of the evaluation were overwhelmingly positive. One attendee wrote, “This was the most outstanding professional development experience of my 7 year tenure in full time college teaching.” Another wrote, “I actually found myself thinking during the lectures and dissections how I was going to incorporate everything in my anatomy course.” We asked participants of the 2015 course who had previously attended the 2014 course to describe how the workshop had impacted their teaching over the previous year. The common response was that these teachers were able to incorporate more clinical correlations into their instruction.

### Table 2: Sample items from the 2015 pre- and post-test assessments

**Directions:** Choose the best answer for each question below.

1. Injury to what nerve will affect the serratus anterior muscle and present with a winged scapula?  
   (A) Axillary nerve  (B) Long thoracic nerve  
   (C) Thoracodorsal nerve  (D) Musculocutaneous nerve

2. Which of the following muscles is innervated by a cranial nerve?  
   (A) Deltoid  (B) Supraspinatus  (C) Trapezius  
   (D) Pectoralis major

3. Which of the following is NOT a branch of the axillary artery?  
   (A) Deep brachial (profunda brachii) artery  
   (B) Posterior circumflex humeral artery  
   (C) Thoracoacromial trunk  (D) Subscapular artery

4. What is the most commonly fractured carpal bone?  
   (A) Lunate  (B) Trapezium  (C) Hamate  (D) Scaphoid

5. Which of the following muscles is NOT part of the rotator cuff?  
   (A) Supraspinatus  (B) Teres major  
   (C) Teres minor  (D) Subscapularis

![Figure 2: Pre-test and post-test assessments. Attendees of the GATE mini-course were given a 10-question, multiple choice assessment at the beginning and end of the mini-course to evaluate short-term knowledge outcomes. The asterisks indicate statistical significance (P<0.001).](image-url)
### Table 3: Post-course survey of GATE mini-course.

<table>
<thead>
<tr>
<th>Survey Item</th>
<th>Faculty (n=40)</th>
<th>Trainees (n=20)</th>
<th>All (n=60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall, my impression of this course was:</td>
<td>4.98 (0.16)</td>
<td>4.80 (0.41)</td>
<td>4.92 (0.28)</td>
</tr>
<tr>
<td>Coverage of the content was:</td>
<td>4.88 (0.33)</td>
<td>4.65 (0.59)</td>
<td>4.80 (0.44)</td>
</tr>
<tr>
<td>Quality of the presentations by faculty was:</td>
<td>4.90 (0.30)</td>
<td>4.65 (0.75)</td>
<td>4.82 (0.50)</td>
</tr>
<tr>
<td>Opportunities to interact with other attendees were:</td>
<td>4.67 (0.53)</td>
<td>4.55 (0.69)</td>
<td>4.63 (0.58)</td>
</tr>
<tr>
<td>Course materials distributed and presented were:</td>
<td>4.85 (0.43)</td>
<td>4.70 (0.47)</td>
<td>4.80 (0.44)</td>
</tr>
<tr>
<td>Quality of the physical space and resources was:</td>
<td>4.85 (0.43)</td>
<td>4.75 (0.44)</td>
<td>4.82 (0.43)</td>
</tr>
<tr>
<td>The appropriateness of the cost was:</td>
<td>4.72 (0.60)</td>
<td>4.47 (0.64)</td>
<td>4.65 (0.62)</td>
</tr>
</tbody>
</table>

1, poor; 2, fair; 3, average; 4, good; 5 exceptional; Mean (SD)

GATE, Gross Anatomy for Teacher Education

### Table 4: Post-course survey of GATE anatomy knowledge and interest.

<table>
<thead>
<tr>
<th>Survey Item</th>
<th>Faculty (n=40)</th>
<th>Trainees (n=20)</th>
<th>All (n=60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>My knowledge of anatomy has:</td>
<td>2.79 (0.41)</td>
<td>2.80 (0.41)</td>
<td>2.80 (0.41)</td>
</tr>
<tr>
<td>My level of interest in anatomy has:</td>
<td>2.95 (0.22)</td>
<td>2.50 (0.76)</td>
<td>2.80 (0.52)</td>
</tr>
<tr>
<td>My level of interest in anatomy education has:</td>
<td>2.95 (0.22)</td>
<td>2.45 (0.69)</td>
<td>2.78 (0.49)</td>
</tr>
</tbody>
</table>

1, not improved; 2, partially improved; 3, greatly improved; Mean (SD)

GATE, Gross Anatomy for Teacher Education

### DISCUSSION

We have provided an opportunity for current as well as future anatomy educators to experience gross anatomy in the same way that medical students and other graduate health science students experience anatomy through cadaveric dissection. This experience is valuable to high school and post-secondary educators for two primary reasons. First, it provides a mechanism for them to further their own education. Continued learning through professional development is important for professional educators. By attending the GATE mini-course, these educators have deepened their own knowledge base in clinical anatomy, and they have gained a better appreciation for anatomical variation, fascial planes, and three-dimensional relationships in anatomy. Second, it provides an opportunity for these educators to improve their instruction. Throughout the mini-course, we emphasized clinical correlates to help stress the importance of understanding anatomy. Examples of these clinical correlates have included Horner’s syndrome for the autonomic nervous system, Erb’s palsy for the brachial plexus, and ulnar claw hand for ulnar nerve injuries and functions of the muscles in the flexor forearm and hand. Taking these newly learned clinical correlates back to the high school and college classroom was the most common way that attendees reported the GATE workshop impacting their teaching. Attendees also cited improved depth of knowledge and team-based learning as positively impacting their instruction.

Attendees of the first two years of the GATE mini-course have included trainees and educators from a wide array of backgrounds including a retired physician who is now teaching at a community college as a second career, a veterinarian-turned anatomy & physiology educator, an anatomy laboratory manager at an osteopathic medical school, and Ph.D. students studying ergonomics, microbiology, and rehabilitation sciences. Bringing together educators and trainees from a wide array of backgrounds to study anatomy was one goal of the GATE series. These interactions have allowed the sharing of classroom instructional ideas as well as job and career networking.

Interestingly, faculty from 2-year community colleges have represented the largest group of GATE attendees. Community colleges employ a combination of master’s level and doctorally-trained biologists to teach freshman and sophomore level courses including the two-semester sequence in anatomy and physiology. Most community colleges offer a large number of anatomy and physiology sections each semester as these courses are foundational courses for most health science areas including nursing. We found that many faculty from state community colleges only teach anatomy and physiology, and some of them have...
never taken a formal course in anatomy. Of the 9 community college faculty in attendance at the 2014 GATE mini-course, 6 returned for the 2015 course and 2 more planned to attend but were unable at the last minute. These data indicate a particular need for anatomy professional development for this sector of anatomist-educator.

As anatomists wrestle with the challenges of training quality educators to fill positions at all levels of secondary and higher education, we hope that GATE will be of interest to other major universities. The time commitment on the part of faculty and staff to conduct GATE is limited for this 3-day mini-course, which makes it a reasonable model for providing professional development to nearby schools, colleges, and universities. Our anatomy faculty look forward to the GATE course each summer. It is refreshing to interact with fellow anatomy educators that are deeply interested in learning and who can share their own ideas and experiences with us.

AKNOWLEDGEMENTS

The authors thank Dr. Steve Zehren and Dr. David Resuehr for their contributions to instruction in the GATE mini-courses. The 2015 GATE mini-course was funded in part by an education outreach grant from the American Association of Anatomists.

Literature Cited


About the Authors

Austin Doss is a senior medical student at the University of Alabama at Birmingham School of Medicine. In June 2016, he will begin his medical training in pediatrics at the University of Alabama at Birmingham / Children’s of Alabama with an interest in critical care. While not in the hospital, Austin enjoys spending time outdoors. Snowboarding, water skiing, and running are some of his favorite pastimes.

Dr. William Brooks is an Associate Professor in the Department of Cell, Developmental and Integrative Biology at the University of Alabama at Birmingham School of Medicine. He is director of the Gross Anatomy Lab and Surgical Anatomy Lab and content leader for medical gross anatomy. He also teaches gross anatomy and neuroanatomy to dental, optometry, occupational therapy, and physical therapy students. His research interests are in the application of team-based learning (TBL) in medical education. Brooks spends his free time with family and church activities.
Myths of Active Learning: Edgar Dale and the Cone of Experience

Jon Jackson, PhD
Fellow in History and Philosophy of Science, Institute for Philosophy in Public Life
University of North Dakota, Grand Forks, North Dakota, 58201

Abstract
Almost all of us who have been teaching for any length of time have by now come across a famous figure titled “the Cone of Learning,” which posits that we remember only 10 percent of what we read, 20 percent of what we hear, and so on. This article shows the origins of this modern myth of active learning, and tries to place the truth into a larger educational context.

Key words: Cone of learning, active learning, discovery learning

Recently, while visiting a major research university as a consultant, I came across the following diagram taped to the file cabinet in one of the faculty offices:

Figure 1. (photo by author).

It jogged my own memory from numerous faculty development workshops in the last decade where some person or another was touting a similar kind of diagram or schema for getting the workshop participants to understand the powerful positive effects of active learning or its cousin, service learning, on student’s ability to learn deeply.

To his credit, my colleague, the professor, on whose file cabinet the graph in question was affixed, was also aware of the following: that the entire argument of “average retention rates” as a function of teaching method is nothing more than an out-and-out fabrication. Despite this fact, it would seem that this diagram has gone all over the world — the figures below exemplify what this particular meme has evolved into — you can even find versions in Chinese and Farsi (see Figure 2).

Figure 2. Dale’s Cone of Experience (both mislabeled and misattributed) in (A) English and (B) Farsi.
The pyramid itself was based on something that became known as “Dale’s Cone of Experience” — itself an admirable and powerful idea in its time. But important to the discussion of education strategies, education research, and pedagogy in general, Dale assigned no numbers whatsoever to his cone. Rather, like Bloom’s taxonomy, the cone described a continuum of learning. In this case however, the cone’s descending levels represented increasingly involved (or in Dale’s terms, “concrete”) learning experiences that Dale envisioned would place watching an educational film into a larger context of concrete learning experiences. How the percentages came about, and how the “cone” morphed into something that got mashed up with our current pyramidal notion of Bloom’s taxonomy has been detailed elsewhere (Thalheimer 2006). This article is worth tracking down and worthy of reading if only to get the important and distinct contexts of these very different frameworks of understanding. (It also serves as a fine introduction to the scholarship of forgetting, which is an important reciprocal function of learning.) While many of you are also aware of the numerous problems behind these infamous graphs and the use of them to set and drive educational policy decisions, it’s not likely that you know much about who Edgar Dale was.

Who was Edgar Dale, and what is the Cone of Experience?

Edgar Dale, who was born in Benson, MN, was a product of west-central Minnesota at the turn of the last century. By the time of his retirement many years later, he was a beloved and celebrated professor of education at the Ohio State University, and was the subject of a special issue of an educational journal (Wagner 1970). In fact, so renowned was Edgar Dale that it was only a matter of time before some of his ideas were co-opted and corrupted into messages and conclusions that were never associated with his published writings.

Edgar Dale received two degrees from the University of North Dakota. His BA dates to 1919 (when the UND Fighting Hawks were known as the “Flickertails”). His 1924 M.A. thesis, titled “Vocational Guidance,” reflects in part the education he received after graduating with his BA, specifically the years he spent as a teacher in a small, rural school, and a later experience as a school superintendent in Webster, ND* (Wick 1988), where the long-abandoned school house has recently received a makeover (Figure 3).

After receiving his MA, Dale left North Dakota for Illinois, where he taught junior high school students in the Chicago suburb of Winnetka while working on a PhD at the University of Chicago. As opportunity presented itself, he went to work for Eastman Kodak as an editor of training films while he finished work on his dissertation. Like so many Americans of his time, Dale was fascinated with the emerging motion picture industry. His interests however, lay beyond the mere aspect of entertainment. Dale recognized early on the pedagogical power that film represented. In 1933, less than 6 years after the first full-length “talkie” film from Hollywood (Figure 4), Dale published a seminal book that sought to empower viewers, and which became the basis of an education-based, anti-censorship movement (Dale 1933, Nichols 2006).

At the peak of his long and storied career, Edgar Dale was considered an expert on the use of media in educational settings, and on the teaching and developing of critical appreciation for all aspects of the media by society at large (Dale 1946). He was regularly featured on panels discussing the impact of media and its representations on how society teaches itself about the world. Some of his regular panel colleagues were the likes of Marshall McLuhan, Alexander Woollcott, and William Paley. Among his professional honors was induction into the National Reading Hall of Fame; the media center at the Ohio State University’s College of Education is named for Dale, as are the faculty awards for teaching and research at the University of North Dakota.

Figure 3. The renovated schoolhouse in Webster, ND.

Figure 4. Promotional poster for The Jazz Singer (1927), the first motion picture with synchronized sound.

Figure 5. Edgar Dale
The original Dale’s Cone of Experience, rather than addressing issues of how we forget things we are taught (as the modern-day cone would suggest), was instead a means of understanding and categorizing how students develop concrete experiences, from which Dale hypothesized deeper learning occurs. It seems that today, over seventy-five years later, Dale’s notions are self-evident; while he worked on training films during the second world war, the power of film to serve as an educational tool for developing critical thinking and deep understanding was something that was not widely acknowledged (Nichols 2006). That he never compared ways of experiencing in a numerical context does not diminish the descriptive force of the original cone of experience. For all of its descriptive power of categorizing learning experiences, the cone does not address student engagement at all. Many concrete learning experiences can yield little or no deep learning for a disengaged student; a problem with which many HAPSters are all too familiar. Dale’s academic work sought to find ways to blend the varieties of concrete learning experience together with heightened student motivation and engagement, a reminder that sometimes the more things change in education, the more they remain the same.

* Webster, ND — a now-unincorporated village of ~130 souls, about twenty miles north of Devils Lake, ND and incidentally, about 30 miles east of Cando, ND – home of the world’s slowest Dairy Queen (Jackson, unpublished data).

**Literature Cited**


**About the Author**

Jon Jackson has taught anatomy and physiology and the history of science for the past twenty years. He is the Western Regional Director of HAPS and a Fellow in the History and Philosophy of Science at the Institute for Philosophy in Public Life.
The Dissected Pelvis: A Classroom Tool to Help Students Discover the Pelvic Cavity and Perineum

Sally Jo Detloff1, Domenick P. Addesi2, Albert Coritz3, Daniel Olson4,1, Robert McCarthy1

1Department of Biological Sciences, Benedictine University, Lisle, Illinois 60532   Sally_Detloff@ben.edu
2D.A. Tool & Machine, Inc., 415 West Glenside Avenue, Glenside, PA 19038   dpaddesi@datoolinc.com
3Electron Microscopy Sciences, 1560 Industry Road, Hatfield, PA 19440   ACoritz@emsdiasum.com
4Department of Biological Sciences, Northern Illinois University, DeKalb, Illinois 60115   drolson@niu.edu

Abstract
For beginning anatomy students, the pelvis of a prosected cadaver is one of the most mystifying and confusing areas of the body to learn and understand. While the connections between the pelvis and the abdomen, the pelvis and the anterior thigh, and the pelvis and the gluteal region are clear in prosections, the relationships among organs, nerves, and blood vessels in the pelvic cavity and perineum are harder to see and therefore more difficult to assess and fully appreciate. Although pelvic models offer a solution to this dilemma, most models focus on just one area, making it difficult to visualize muscles, nerves, and vessels in the gluteal and anterior abdominal regions, pelvic cavity, and perineum simultaneously. In this study, we further dissected the pelvis of a male and female cadaver prosections and placed the female pelvis in acrylic to preserve it as a model. We bisected the male pelvis and are currently using this specimen as a teaching aid in human anatomy labs. We are currently evaluating student performance after introduction of the pelvic model in order to test if the model is helpful in improving student understanding of this difficult material.

Key words: pelvic cavity, perineum, pelvis, embedment model, pelvis

DISSECTION
In the fall of 2014, after completing the summer introductory anatomy course offered at Benedictine University, I was considering which aspects of anatomy had proven to be the most difficult to master. One area came to mind before all others: the pelvis. Trying to decipher the ways in which the muscles, vessels and nerves wrapped around each other, entering and exiting foramina and making their way to the lower extremity, proved frustrating. By this time, I was a teaching assistant for human anatomy and I began to contemplate ways that I could improve this part of the course. I did not want students to struggle as much as I did, nor did I want them to feel that this was something they could not master. I also wanted to explore the pelvis and perineum on my own in greater detail. I felt that if I could uncover the mysteries of the pelvic region, it would be helpful to my students and I would be able to bring greater enthusiasm to the topic. Furthermore, I hoped my enthusiasm would be contagious and encourage students to get excited about anatomy. I hoped this would inspire them to study more, which would lead to a greater appreciation for the beauty of the human form.

I knew that the female cadaver in our lab was nearing the end of her time at Benedictine University and needed to be replaced. I formulated an idea to remove the female cadaver’s pelvis to use it as a teaching tool in human anatomy, and presented this idea to my mentor, Dr. Robert McCarthy, who encouraged me to pursue it. I discussed the idea with Dr. Daniel Olson, the head of the cadaver donation program at Northern Illinois University, and obtained permission to use the pelvis for educational purposes. Over winter break of 2014-15, Dr. Olson invited me to Northern Illinois University to dissect the replacement female cadaver for Benedictine University. Dissection provided a hands-on experience that brought anatomy and physiology to life, and I truly enjoyed uncovering all of the structures and finding others that were only discussed in lecture. After that experience, I set to work removing the pelvis and I finished the dissection during spring break of 2015. During the summer of 2015, I removed the pelvis from a male cadaver that was scheduled to be replaced in the fall. I bisected the pelvis, mirroring the work I had done on the female pelvis. The reasoning for preparing two pelvic models was to ensure a viable model in case the speculative part of the project, the embedding process, didn’t work.

I started the dissection with the female cadaver. I began by disarticulating the hip joint, separating the lower extremities from the pelvis by severing the iliofemoral, ischiofemoral, and pubofemoral ligaments externally and the round ligament internally, severing the spine between the third and fourth lumbar vertebrae, and preserving the pia mater and cauda equina (Figure 1A). In the dissections that followed, I consulted Grant’s Dissector (Tank 2012), continued on next page
Netter’s Atlas (Netter 1995), and Clemente’s Anatomy (Clemente 1987) for structure identifications, but did not follow any specific published protocols. Because it had already been prosected, some of the major structures were already evident. After consulting my two mentors, Dr. McCarthy and Dr. Olson, I decided to concentrate on displaying the vessels on the right half of the pelvis (Figure 1B) and the nerves on the left half (Figure 1C).

The uterus, ovaries, and fallopian tubes had been removed during the woman’s lifetime, and I proceeded to remove the descending colon, sigmoid colon and rectum to allow an unobstructed view of the interior of the pelvis. The psoas major and iliacus muscles as well as the external and internal abdominal oblique and transverse abdominus muscles were already dissected and clearly visible. The psoas minor was not present, a variation found in 44% of the population (Bergman et al. 1995-2016). I left the descending aorta with the iliac arteries and the inferior vena cava with iliac veins intact, as well as the femoral and obturator nerves. I was able to reveal the multiple branches of the right internal iliac artery, including the vesicular, middle rectal, internal pudendal, superior gluteal, ilio-femoral, and lateral sacral arteries (Figure 1B).

I removed the left half of the bladder to allow further dissection revealing piriformis, coccygeus and obturator internus from an anterior view, in addition to the levator ani muscles. I completed the dissection of the lumbosacral trunk on the left side by exposing the first four sacral nerves (Figure 1C). I uncovered the urethra and anus and the ischiocavernosus and bulbospongiosus muscles from a superior view. Previous dissection of the gluteal region had exposed the glutaeal muscles with the superior glutaeal

Figure 1. Female pelvis: upon removal from the cadaver (A); right side, showing branches of the internal iliac artery (B); left side, showing obturator nerve and sacral plexus (C)
artery from a lateral and posterior view, in addition to the lateral rotators (piriformis, inferior and superior gemellus and obturator externus). I removed the gemelli muscles to provide a clearer view of piriformis, the obturator externus tendon, and the sciatic nerve. On the left side of the pelvis, I fully exposed gluteus minimus by removing gluteus maximus and gluteus medius. On the right side, I removed the thoracolumbar fascia to reveal the erector spinae muscles, but left the fascia intact on the left to reveal its multi-directional fibers. I removed fatty tissue from the ischiorectal fossa to expose the external anal sphincter muscle and levator ani muscles, and displayed the inferior rectal artery and branches of the pudendal nerve on the left side. Finally, I displayed the sacrotuberous ligament extending from the ischial tuberosity to the sacrum.

I started the dissection of the male pelvis during the winter break of 2015-2016. Before removing the pelvis from the cadaver, I had decided to sever the spine between T12 and L1, to disarticulate the right femur, to sever the left femur about eight inches distal to the hip joint, and to bisect the pelvis (Figure 2A). After this was accomplished, I followed the same process as with the female pelvis, dissecting vessels on the right (Figure 2B) and nerves on the left (Figure 2C). The testicular vein remained intact on the right side allowing for a clear view of the deep inguinal ring. I was also able to show the relationship between the obturator nerve and artery on their course through the obturator foramen. On the right, I exposed the sacral plexus to illustrate relationships between these nerves and the internal pudendal artery and superior gluteal artery. Because I had severed the spine between T12 and L1, I was able to include the iliohypogastric and ilioinguinal nerves in the presentation along with the lumbosacral plexus (Figure 2D). Bisection of the penis provided an additional opportunity for a classroom model of genitalia. I left the penis and associated structures in place on the right side. As the scrotum had been bisected as well, I was able to expose the vas deferens, epididymis and testes (Figure 3A). Removal of all the vessels on the left side allowed for a clear view of coccygeus and the levator ani muscles (Figure 3B). Because I had included a portion of the left femur, the structures of the femoral triangle were able to be appreciated more fully than on the female pelvis.

At this point, I prepared the female pelvis for embedment.

**EMBEDMENT**

I purchased a pint bottle of acrylic and a mold and began to experiment with the embedment process on small biological samples. I contacted Al Coritz at Electron Microscopy Sciences to discuss the handling of the acrylic.

**Figure 2.** Male pelvis: bisected right side, upon removal from the cadaver (A); right side, showing branches of the iliac artery (B); left side, showing lumbosacral nerves (C); left side, showing sacral plexus.
and any complications that might occur. Mr. Coritz referred me to a company that makes custom acrylic molds. I contacted Domenick Addesi of D.A. Tool and Machine and provided a basic schematic of what I needed. He counseled me as to what type of material the mold should be made of and the importance of the thickness of the acrylic material. Initially, I mixed two gallons of acrylic and poured it into the mold to provide a base acrylic plate. Submerging the pelvis in acrylic in a separate container ensured that no air bubbles were formed between the pelvis and the acrylic before making the final pour into the mold. I then placed the pelvis into the mold and fully covered it with acrylic. As the acrylic hardened, it became apparent that this exothermic process was hot enough to melt the remaining fat in the pelvis. Most of this residue floated to the surface and sat on top of the acrylic so that it could be easily removed. Some, however, remained in the acrylic, obscuring the view in a few places. Additionally, some of the acrylic hardened with a non-transparent, “cloudy” surface, and in a few places small pieces of muscle detached from the pelvis as the acrylic hardened, leaving “floaters” in the viewing field.

Unfortunately, because of these issues we would not be able to use the embedded female pelvis in the classroom, so we are focusing on using the dissected male pelvis. In retrospect, this approach recommends itself for several reasons. First, although the sample will not last as long, its ephemeral nature provides an opportunity for a future student to create another model for the University. Second, structures can be clearly marked and tagged for practical examinations on the un-embedded model, which would not have been possible with an embedded pelvis due to optic distortion. Finally, the dissected structures can be modified by instructors or future students to enhance the visibility or placement of particular structures.

PEDAGOGICAL RESEARCH & TEACHING

We are currently using the un-embedded male pelvis in the classroom as a teaching tool. We are testing the efficacy of this model for improving student understanding of pelvic anatomy by comparing scores on practical exam questions in anatomy lab sections using the model to sections that are not using the model. Furthermore, I am working with all the human anatomy instructors at Benedictine to select lecture exam questions from 2014 and 2015 that will be repeated on current (2016) and future lecture exams in order to assess whether this pelvic model increases student understanding of the pelvic cavity and perineum in a lecture setting.

I would like to express my appreciation to HAPS for providing the funding for this project in the form of the Student Scholarship Grant.

**Figure 3.** Male pelvis: bisected right side, showing genitalia (A); left side, pelvic diaphragm (B).

**Literature Cited**


continued on next page
About the Authors

Sally Jo Detloff is an undergraduate student at Benedictine University in Illinois, where she is majoring in Health Sciences and minoring in Chemistry. She is passionate about anatomy, physiology and pathology. She hopes to pursue a master’s degree in biological sciences, with a focus on anatomy, after finishing her BS degree next year.

Dan Olson teaches graduate and undergraduate human anatomy courses full-time at Northern Illinois University. He is also an adjunct instructor teaching human anatomy at Benedictine University. In addition to his teaching duties he is an independent contractor performing anatomical prosections for area colleges.

Robert McCarthy is an assistant professor in the Department of Biological Sciences at Benedictine University in Lisle, IL, where he teaches human anatomy and evolution to undergraduate biology and health science students and oversees the Anatomy Lab and teaching and learning assistant programs. Robert is a biological anthropologist who studies the evolution of speech and language, the primate and hominin skull, and Neanderthal evolution, and has published articles in Journal of Human Evolution, American Journal of Physical Anthropology, PLoS One, Anatomical Record, Handbook of Paleoanthropology, and Archives of Oral Biology.

Photos and Bios for Domenick P. Ad desi and Albert Coritz were unavailable at publishing.
EDU-Snippets: Spring 2016
Snippets – from Planes and Senses to Terms and Props to Rh and Logic. WOW!

EDU-Snippets – A column that survives because you - the members - send in your Snippets

Roberta M. Meehan
GMU
Phoenix, AZ
Edu-Snippets@hapsconnect.org

EDU-Snippets is a column designed to let you, the members of HAPS, share your “ways to make sure your students get it.” Since EDU-Snippets began, our members have been continuously amazed at how many teaching and demonstration ideas pop up and are easily transferred from one instructor to another through Snippets. This edition is no exception. So, our topic for this issue is literally Various Snippets. Hopefully you will be able to utilize what our colleagues have submitted. Hopefully, too, some of the ideas presented here will spur you on so that you can either make alterations to fit your own needs or spark your imagination so that you can come up with your own Snippet ideas, which you can then submit for publication.

I. Plane Snippet

Nina Zanetti (Siena College, zanetti@siena.edu) started this issue of Snippets off with a neat idea for helping our students understand body planes.

To help students understand different planes of section, I have them work in groups. Each group must design an “original” animal and build it in clay, in triplicate. The animal must have several different organs (different color clay), some of which are not visible from the outside. And the animal must have bilateral symmetry. The students in that group then slices (sections) each of their clay animals: one in frontal section, one in cross section, one in sagittal section. Then, another group comes and looks at the sections, and (with never having seen the whole 3-D animal) must describe what the whole animal looks like. We also use these sectioned models as a jumping off point for discussing how to interpret sectioned material, such as histology specimens.

II. Practical Sensory Snippet

Meanwhile Betsy Ott (Tyler Junior College, bott@tjc.edu) was thinking about problems students have with the nervous system.

Students have a hard time pulling together disparate information from the 3 – 5 separate chapters on the nervous system, both anatomically and functionally. So, I have developed an in-class assignment that involves compiling information for a specific pathway from the various chapters.

Students are divided into groups, and each group must choose from events such as the ones on the following list:

- Puncture wound to the right thumb;
- Stepping on a hot coal with the left foot;
- Picking up a soft object with the left hand;
- Tickling the right side of the face.

Each group must compile, in a poster, the steps involved in the sensory neural pathway specific to both the location of the stimulus and the type of stimulus. This requires researching types of sensory receptors, along with dermatomes, specific peripheral nerves and the associated plexus, specific spinal or cranial nerve roots, and specific spinal cord or cranial tracts, and following the pathways through the brain to the specific region of the cerebral cortex that maps to the body part stimulated. Students have to study diagrams and tables in the textbook, in addition to reading the relevant text.
III. Pronating and Supinating Snippet

Randyl Rohm (Purdue University Calumet, randyl.rohm@purduecal.edu) sent in two ways to help students differentiate between pronation and supination. It seems that this should be the start of an ongoing list of “opposite” terms that students often get confused. You are welcome to contribute your own and EU-Snippets will be glad to compile and publish them.

To remember pronation/supination I tell my students:

A pro plays basketball (and I demonstrate by having my hand down bouncing a basketball)

If you are a waitress, you serve soup (and I demonstrate by having my hand up holding a food tray).

IV. Volumetric Cardiac Snippet

Jennifer Hillyer (Aultman College of Nursing and Health Sciences, Jennifer.hillyer@aultman.com) has several ideas for helping students understand volumetric changes during the cardiac cycle.

To help students visualize the volume changes during a cardiac cycle small groups of students are given a water bottle and a balloon. Each water bottle has a different volume marked on the outside to represent the end-diastolic volume of a ventricle. The group is instructed to attach the balloon to the opening of the water bottle and squeeze as much water as possible into the balloon. The balloon’s volume represents the stroke volume ejected by ventricular systole; each balloon also has a volume marked on the outside. Students are then asked to calculate the end-systolic volume left in the water bottle (i.e., the ventricle).

Positive and negative inotropic agents are then discussed using the water bottles and observing the relationship between each agent’s impact on the stroke volume and cardiac output when the heart rate stays the same. Students are also asked to calculate how the heart rate might change in response to each of these agents in order to maintain the same cardiac output.

Another way I use a water bottle and balloon in the classroom is to illustrate the impact of an increased afterload on the heart. I typically use a plastic bottle with a removable cap that has a smaller hole, such as a plastic salad dressing bottle. A student comes forward and is asked to squeeze the water bottle without the cap to simulate ventricular systole as the water moves into the balloon (showing the stroke volume). Then the student is asked to use the same amount of force to move water from the bottle with the small hole in the cap into the balloon to illustrate how the afterload changes when there is stenosis of a semilunar valve. The students are able to visualize how the stroke volume decreases and the end-systolic volume is higher in patients who have this condition. Overall, students appear to be less intimidated by the math and terms associated with the volume changes during the cardiac cycle when they have a visual aid that they can manipulate (and make water balloons in the process).

V. Rh Snippet Exercise

Ann Raddant (St. Ambrose University, RaddantAnn@sau.edu) came up with a great idea for helping our students understand Rh problems with pregnancy and newborns. This understanding can definitely be a problem. Even on TV shows this concept is sometimes stated backwards. So, Ann said…

Here is an exercise for checking students’ understanding of the hemolytic disease of the newborn. They will have watched a video lecture before coming to class. I have cut apart the attached “events” and will give an envelope full of them to the students. The only event that I will hold back is “Mother is administered Rhogam”. Students are instructed to put together the correct list of events that could lead to erythroblastosis fetalis in the 2nd pregnancy. After they complete that, I will give them the Rhogam event, and instruct them to change all downstream events appropriately.

- First pregnancy: Rh+ female is pregnant with Rh- baby
- First pregnancy: Rh- female is pregnant with Rh+ baby
- First pregnancy: Rh+ female is pregnant with Rh+ baby
- Second pregnancy: Rh+ female is pregnant with Rh- baby
- Second pregnancy: Rh- female is pregnant with Rh+ baby
- Second pregnancy: Rh+ female is pregnant with Rh+ baby

There are images like all of these that students often get confused. You are welcome to contribute your own and EU-Snippets will be the start of an ongoing list of "opposite" terms that students often get confused. You are welcome to contribute your own and EU-Snippets will be glad to compile and publish them.

To remember pronation/supination I tell my students:

A pro plays basketball (and I demonstrate by having my hand down bouncing a basketball)

If you are a waitress, you serve soup (and I demonstrate by having my hand up holding a food tray).
• Mother is administered Rhogam
• Mother does not secrete anti-Rh antibodies Anti-Rh antibodies bind to and block mom’s immune system from recognizing Rh antigen
• During delivery, hemorrhaging at the placenta leads to fetal blood mixing with mother’s blood
• Mother develops anti-Rh antibodies
• Mother is exposed to Rh antigens
• Mother is exposed to Rh antibodies
• Anti-Rh antibodies from the mother cross the placenta
• Anti Rh antigens cross the placenta
• Fetal red blood cells are targeted and destroyed

VI. Avascular Necrosis of Bone Snippet
And finally, Mary Scott (Dodge City Community College, mscott@dc3.edu) had a great idea on a topic we don’t usually think about – and an idea that we really can all integrate into our classes. Mary said…
I just reviewed an article on avascular necrosis of bone, and was excited since I like to use this in both bone and endocrine units. That reminded me of http://www.aafp.org/afp/2014/1215/p843.html, an article that I like to use to talk about DDH to help my students connect what they are learning or to give them reasons why they have to know more than just general bone names.

A Packed Lesson
Recently I was reminded of how using primary sources can enrich and go beyond the anatomy and physiology classroom even as we are establishing a foundation of knowledge. I try to have my students compare and contrast the hip and shoulder joint before they may have had a chance to read about it. (Which is stronger? More mobile? Easier to dislocate?) I want them to practice their observation skills. Then, I can ask them what they think would happen if the acetabulum was not a deep socket. This leads us to a discussion of the fetal development of the acetabulum and developmental dysplasia of the hip. Here is a link to an article on developmental dysplasia of the hip: http://www.aafp.org/afp/2014/1215/p843.html) I have found this fairly easy for my students to understand, and it leads to a variety of discussions.

The article leads to more questions and the need for more research. I use this as an example of how information changes and why they will need to plan to have regular professional development for their future health careers. This works into ethics questions of whom to treat, when to best treat, and the ethics of how to study this problem further. It can also bring up a discussion of why old treatments (such as double or triple diapering) may have been ineffective (unable to hold the femoral head in the acetabulum in a consistent pattern).

VII. And We Hope You Will….
Keep those cards and letters coming (right to our Edu-Snippets@Hapsconnect.org address)! Thank you all for your EDU-Snippet contributions. The influx of Snippets has been good! Please keep it up because more are always needed! Your ideas are tremendous! If you have thoughts or ideas, or any other interesting ways – any inspirations at all, great or small – to help our students understand anatomy and physiology, EDU-Snippets would love to hear from you! Once again, EDU-Snippets encourages new submitters to submit – and regulars to keep on contributing! If you’ve got some Snippets, please share them with us. You will also find a reminder on the HAPS-L list. But, plan ahead. You can even submit your ideas now and maybe next issue you too will see your EDU-Snippet in print! Perhaps you even have a suggestion for a Snippet theme! If that sparks a challenge, send in a Snippet!!

Dr. Roberta Meehan is a semi-retired science educator presently involved in tutoring and professional writing. Among other literary endeavors, she has written 17 science books and manuals and two non-science books. She has also written for, edited, copy edited, and done various types of analyses for most of the major publishing houses. She has been on the HAPS Editorial Board for 14 years and has been involved with EDU-Snippets for almost that long. Roberta lives with her dachshunds in Phoenix, Arizona.

Back to TOC
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Robert Tallitsch, Chair
This committee is charged with developing, reviewing, and recommending policies and position statements on the use of animals in college-level A&P instruction.
rtallitsch@hapsconnect.com

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Melissa Carroll, Chair
This committee is charged with developing, reviewing, and recommending policies and position statements on the use of cadavers for human anatomy and physiology education in colleges, universities and related institutions.
mcarroll@hapsconnect.org

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wriggs@hapsconnect.org

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elathrop@hapsconnect.org

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tthompson@hapsconnect.org

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bott@hapsconnect.org
tlehman@hapsconnect.org
ttthompson@hapsconnect.org

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Peter English
peter@hapsconnect.org

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dkelly@hapsconnect.org
rcrocker@hapsconnect.org

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khull@hapsconnect.org
editor@hapsconnect.org

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peter@hapsconnect.org

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kross@hapsconnect.org

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Valerie O’Loughlin, Chair
This committee consists of an experienced advisory group including all Past Presidents of HAPS. The committee advises and adds a sense of HAPS history to the deliberations of the BOD
voloughl@hapsconnect.org

SAFETY
Yuli Kainer, Co-Chair
Neal Schmidt, Co-Chair
This committee develops standards for laboratory safety. The committee maintains a variety of safety documents available for download.
ykainer@hapsconnect.org
nschmidt@hapsconnect.org

STEERING
Ron Gerrits, Chair
This committee consists of all committee chairs. It coordinates activities among committees and represents the collective committee activity to the HAPS BOD.
rgerrits@hapsconnect.org

TESTING
Jennifer Burgoon, Co-Chair
Valerie O’Loughlin, Co-Chair
This committee has completed, tested and approved the HAPS Comprehensive Exam for Human A&P and is developing an on-line version of the exam.
jburgoon@hapsconnect.org
voloughl@hapsconnect.org

2016 CONFERENCE COORDINATORS
Kyla Ross, Co-Chair
Adam Decker, Co-Chair
The committee chairs invite input from HAPS members and willingly provide information on the activities of their committees.
kross@hapsconnect.org
adecker@hapsconnect.org

Click here to visit the HAPS committees webpage.