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Helping students make sense of physiological mechanisms: the “view from the inside”

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Modell HI. Helping students make sense of physiological mechanisms: the “view from the inside”. *Adv Physiol Educ* 31: 186–192, 2007; doi:10.1152/advan.00079.2006.—Students often view physiological mechanisms in descriptive terms from a perspective that does not help them recognize causal relationships. The “view from the inside” is a technique that helps students focus on causal relationships from the “viewpoint” of a reporter standing inside of the system. Qualitative data indicate that the technique helps students to recognize the applicability of general models in physiology, make sense of difficult physiological mechanisms, and develop learning strategies that they apply to other disciplines. The technique is also useful in helping students recognize conceptual or reasoning difficulties in their mental models (misconceptions).

mental model building; physiological mechanisms; active learning; meaningful learning; frame of reference

MOST PHYSIOLOGY INSTRUCTORS will agree that the goal of physiology education is to help students make sense of physiological mechanisms so that they can apply this knowledge in the pursuit of health-related careers or in relation to health-related issues that arise in their everyday lives. However, instructors are faced with a number of significant challenges that often limit the success with which they are able to reach this goal.

The first challenge lies in the way in which most students approach learning. To these students, learning is about acquiring information. However, if the goal is to apply the information, learning must involve making sense of the information and building mental models that provide a framework for problem solving (meaningful learning). Most physiology texts, especially undergraduate texts, support the former type of learning but not the latter. These texts are descriptive in nature, telling the student “the story” without focusing on the causal relationships that are necessary to make sense of the mechanisms. Students focus on what happens rather than how it happens. They typically learn the story with the expectation that they will have to retell the story rather than use the relationships to solve problems. The result is that they seldom understand causal relationships sufficiently to allow them to solve problems. Without addressing the causal relationships, this approach can also often lead to misconceptions about the mechanisms.

Consider the cardiac cycle, for example. Students learn that blood flows from the left atrium to the left ventricle and then to the aorta. Furthermore, a valve separates the atrium from the ventricle and the ventricle from the aorta. At some point in time the atrium contracts, and at a later point the ventricle contracts. The sequence that students remember is that the

atrium contracts, a valve opens, blood flows into the ventricle, and the ventricle contracts, causing another valve to open and blood to flow into the aorta. They focus on the timing of the events rather than the pressure relationships that cause the valves to open and blood to flow.

Michael et al. (7) polled 683 undergraduate students in physiology prior to the students covering the cardiovascular system in their physiology course. It is reasonable to assume that these students had been exposed to the sequence of events in the cardiac cycle as part of their high-school biology experience or, perhaps, in a general biology course prior to their taking physiology. Approximately two-thirds of these students thought that the ventricle fills only when the atrium contracts or only when the papillary muscles contract and open the atrioventricular valve. Michael et al. did not retest students following the course component covering the cardiovascular system. However, our experience with students holding this misconception indicates that this idea is very persistent and that a significant number of students retain the misconception even after the cardiac cycle is covered in the course.

A second challenge is presented by the fact that students in physiology must routinely examine phenomena at different levels of complexity (9) and from different points of view. In some circumstances, the focus is at the cellular level (e.g., membrane transport); in others, the focus is at the tissue level (e.g., water movement across capillary walls); and, in still others, the focus is at the organ (e.g., determinants of cardiac output) or systemic (e.g., gas transport) levels. In addition, students must be able to shift their focus among these levels of complexity depending on the phenomenon being considered or the problem to be solved. When faced with this challenge, many students are unable to choose an appropriate frame of reference from which to view the aspect of the mechanisms under consideration. They tend to want to focus on the “big picture” and the fine details at the same time.

I have adopted a technique to help students choose an appropriate frame of reference and, by doing so, restrict their focus to the relevant aspects of the mechanism or system under study. Although I use the technique routinely with first-year medical students, I have found it useful with undergraduate populations and, in workshop settings, with undergraduate instructors. In most discussions of a mechanism or system, students choose a frame of reference in which the view is from the “outside” of the system in question. For example, the picture that comes to mind when discussing the cardiac cycle is a two-dimensional cutaway view of the heart, similar to that

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shown in Fig. 1, with the observer looking at the atria, valves, ventricles, and aorta all in the field of view.

In the approach described below, the student views the system from the “inside.” The view is restricted to what can be observed from the designated vantage point, and events are seen as they occur “around” him/her. For example, instead of viewing blood flowing through vessels, the student becomes an observer within the vessel, “seeing” flow coming toward him/her, “seeing” flow going away from her/him, “feeling” changes in pressure, and “seeing” changes in the caliber of the vessel.

The change in perspective is easily recognized by considering what one experiences when watching television coverage of a NASCAR auto race. The majority of the coverage shows cars moving around the race course from vantage points along the track. However, from time to time, the picture switches to images from cameras mounted in or on the car, and the viewer sees the race track from the perspective of the driver. An equivalent experience may be provided in a high-technology environment by developing virtual reality models. However, high-technology environments are not required to achieve the goal. The student needs only to use his/her imagination to “experience” what is happening at the chosen vantage point and examine how his/her current knowledge base relates to the causal relationships inherent in the mechanism under study. Because the technique is easily applicable to problems in other disciplines (see *Transference of the technique to other disciplines*), it provides students with a powerful strategy for improving problem-solving skills. Discussion among a group of viewers provides an additional opportunity for group members to test their individual mental models and arrive at a consensus view of the events and the causal relationships from which those events result. This view can then be compared with “real world” data to determine if the model provides accurate predictions of real events.

An Example

A schematic diagram of the aspect of the system under discussion is provided for the student with one or more view-

points indicated (Fig. 2). Members of the group are directed to serve as “reporters” at each viewpoint. Each reporter describes the events that they observe (or experience) from their viewpoint. It is important that the students recognize that they only have a limited view from their viewpoint. For example, if the viewpoint is in the left ventricle, the reporter cannot see into the left atrium or aorta unless the appropriate valve is open. The exercise begins by choosing a point in time with each reporter describing the events occurring *at that time* as seen from his/her reporting station. By comparing events at the different reporting stations and considering the factors causing the events, the relevant mechanism(s) is elucidated.

The following example exercise is designed to help students make sense of events in the cardiac cycle. The exercise follows a unit on cardiac physiology in which students examine the electrical and mechanical properties of cardiac muscle, gross anatomy of the heart, and basic features of the electrocardiogram (ECG). Prior to this unit, students have discussed, in a variety of contexts, the mass and heat flow (gradient-flow-resistance) general model (8).

Student reporters are stationed in the left atrium, left ventricle, and aorta (Fig. 2A). The students are presented with a set of axes on which to plot left atrial pressure, left ventricular pressure, aortic pressure, and left ventricular volume as functions of time. An ECG trace is provided to establish a reference time base for events of the cycle (Fig. 3). Students are instructed to choose a time point on the ECG and receive “reports” from each viewpoint at that point in time. Example questions that this reporter would be expected to answer are as follows: “If you look up toward the pulmonary vein, what do you see? Is there flow? If there is flow, how must the pressure in the pulmonary vein compare with the pressure where you are standing? Look down toward the ventricle. What do you see? Is the valve open? If so, why is it open? Is there flow leaving the atrium? How does the pressure where you are standing compare with the pressure in the ventricle?” The reporters in the ventricle and aorta answer a similar set of questions to report events that can be observed from their vantage points.

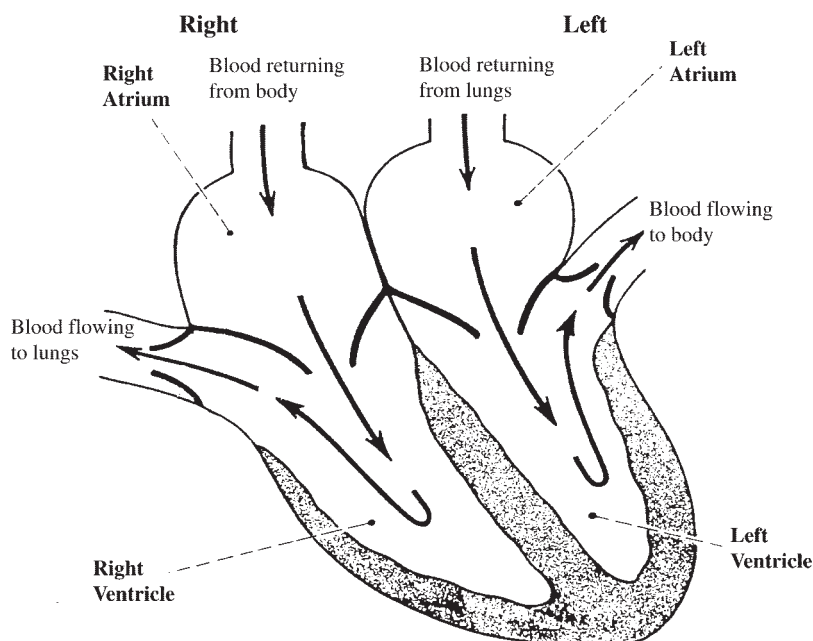


Fig. 1. Schematic diagram of the heart for discussing the cardiac cycle. [Adapted from Ref. 4.]

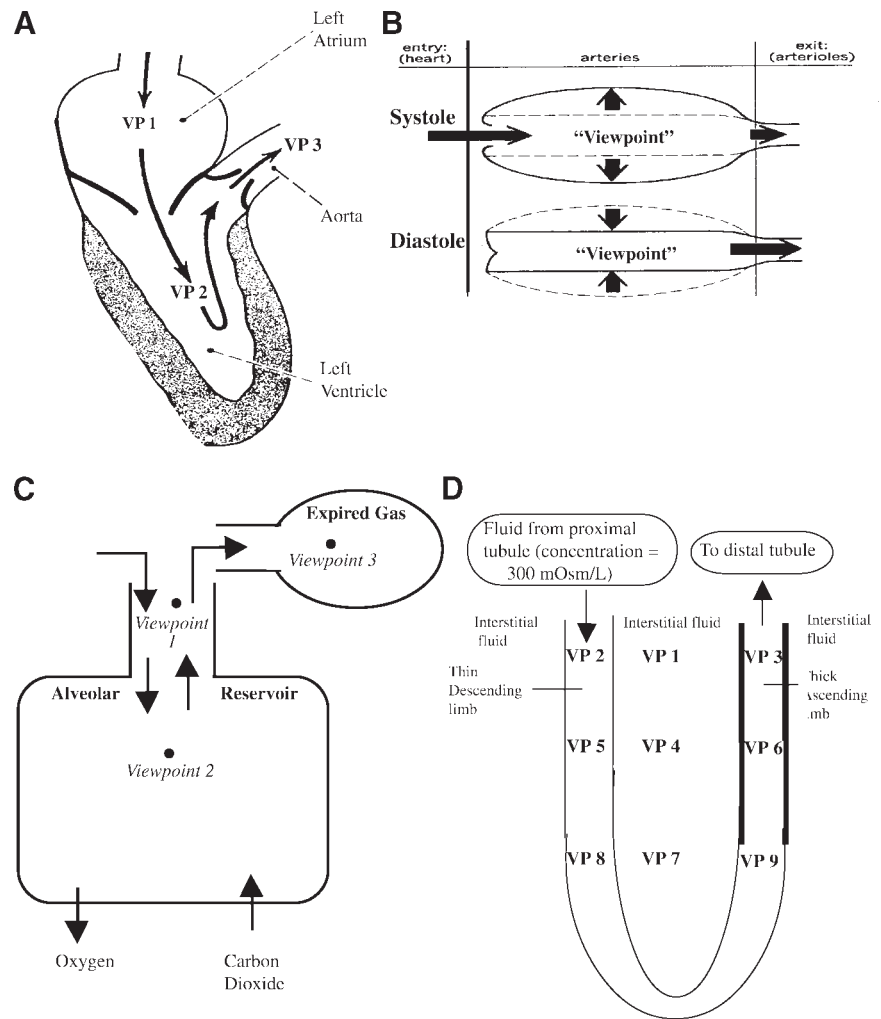


Fig. 2. Sample diagrams indicating viewpoints (VP) from “view from the inside” exercises. A: cardiac cycle. [Adapted from Ref. 4]. B: arterial blood pressure. [Adapted from Ref. 11.] C: alveolar gas exchange. D: countercurrent multiplier in the loop of Henle.

The students then move to a subsequent point in time and repeat the process. At each point in time, they are to plot relative values for left atrial pressure, left ventricular pressure, aortic pressure, and left ventricular volume on the axes provided. By the end of the exercise, they have generated the classic Wiggers diagram that is presented in most textbooks of physiology. Following the exercise, the students are presented with a correctly drawn Wiggers diagram to test their predictions of the pressure relationships and volume changes occurring during the cardiac cycle.

Caveats About the Technique

Students must be coached. Although the premise of the technique is simple, successful implementation may require coaching for some students. Students are accustomed to learning the story. Hence, instead of reporting on events, they interpret instructions related to making observations as opportunities to tell the story. Hence, instead of reporting on events, they approach the task in one of several ways. They may offer a description of events similar to what they recall from their textbook or class notes. In doing so, they miss important causal steps in the mechanism being examined that are not included in the textbook description. Another way that some students approach the task is to anthropomorphize elements of the

mechanism or apply teleological reasoning to the process. For example, when reporting on ion flow across a membrane, a student may say, “sodium needs to move inside the cell to depolarize the membrane, so gates open.”

In a third approach, students fail to focus on an appropriate time frame. For example, in the cardiac cycle exercise, instead of choosing a time reference point on the ECG trace and reporting on events occurring at the three viewpoints at that point in time, they describe the events at each viewpoint during the complete cycle (in essence, repeating the story that was described in the text). This results, of course, in failure to recognize the relationship between pressures in the atrium and ventricle and pressures in the ventricle and aorta.

In another exercise focused on propagation of an action potential along an axon, viewpoints are chosen in the extracellular and intracellular compartments at three locations (*regions 1–3*) along the cell membrane. In *region 1*, an action potential has just completed; in *region 2*, an action potential has just been initiated (i.e., threshold has just been reached); and in *region 3*, the membrane is at rest. The exercise begins with the extracellular reporter in *region 2* reporting on events within his/her view. The appropriate response is that positive ions (sodium) are flowing from the viewpoint into the cell because channels in the membrane have opened, and a gradient for

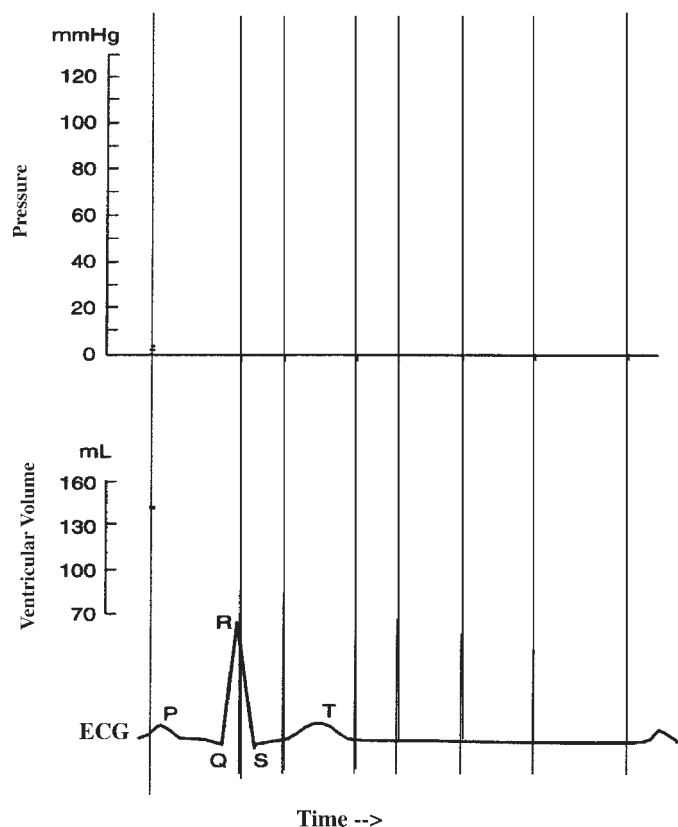


Fig. 3. Axes provided to students for the cardiac cycle exercise. Students are instructed to choose points along the time axis and, using the ECG as a guide to ventricular muscle activity, generate a Wiggers diagram. Scales are provided as a reference for qualitative predictions (see text).

these ions exists from the outside to the inside of the cell. When looking toward *region 1*, this reporter sees positive ions moving toward her/him because a gradient between these two regions has been established by the movement of positive ions into the cell. Similarly, when looking toward *region 3*, the reporter sees positive ions moving toward him/her. The more frequent response from the student stationed in *region 2* is a textbook description of the sequence of events in the action potential without regard to the prescribed time frame. A consequence of this is that the student either doesn't consider extracellular ion flow from *regions 1* and *3* or doesn't recognize that the ion flow from *region 3* to *2* contributes to the depolarization of the membrane in *region 3*.

Several steps can be taken to address these issues. First, when introducing the technique to the class, include a discussion focusing on the difference between the role of a news reporter and a news commentator and emphasize that the student's job in this exercise is to report the events, not interpret them; this distinction can be very helpful.

Providing students with sample questions to answer when reporting on events helps provide them with a model of the process. Sample questions for the cardiac cycle exercise were presented above. Coaching with these questions can be done as students work in small groups or when the class works together in a whole class discussion. In my class, students work in small groups on an exercise as a prelude to a whole class discussion. The small-group discussion gives the students time to become familiar with the task at hand, helps them make their current

mental model of the mechanism visible, and gives them confidence to contribute to the whole class discussion. Coaching is provided by circulating among the groups and making suggestions as needed to specific groups.

Following the small group work, students volunteer or are chosen to act as reporters. With reporters in place, I ask those at the various viewpoints for their reports, thereby modeling the process further. The class is then engaged in the conversation to determine the causal steps leading to the observations or consequences of the events being reported. For example, in an exercise designed to make sense of arterial blood pressure changes, the reporter "stands" in the aorta (Fig. 2B). At the reporter's left is the aortic valve; at the reporter's right are the downstream components of the arterial tree with the arterioles at the end of the tree. During systole, the reporter sees blood rushing toward her/him from the ventricle and blood flowing away from the viewpoint to the downstream components of the vascular tree. At this point, the reporter might be asked, "How does the blood flow coming to you compare with that going away from you? If more blood is flowing toward you than away from you, what is happening to the volume around where you are standing?" The class may then be asked to predict what the reporter "feels" in terms of pressure at his/her location and the basis for that prediction. Carrying the discussion further, the class may be asked to predict what changes the reporter will see if an element of the system (e.g., downstream vascular resistance or arterial compliance) is increased or decreased.

Students may require specific prior knowledge. Depending on the goal of the exercise, students must have prior knowledge of the elements of the mechanism. For example, students cannot be expected to successfully complete the cardiac cycle exercise without prior knowledge about the electrical and mechanical properties of cardiac muscle and the events reflected by the ECG.

In situations where the "view from the inside" exercise is being used to help students make their current mental model visible (see *Discussion*), the approach does not require specific prior knowledge. In this case, the goal is to provide students with a starting point for their study rather than a culminating activity to integrate information at the end of the unit.

Does the Technique Work?

It is reasonable to predict from the basic premise of the technique that the view from the inside should be effective in helping students make sense of mechanisms. However, where is the evidence that supports this prediction? Unfortunately, for a variety of reasons, we have not conducted carefully controlled quantitative studies to test this prediction. However, since implementing the technique >5 years ago, we have accumulated anecdotal data that indicate that the technique helps students make sense of physiological mechanisms.

For example, in a subsequent cardiac cycle exercise, students are presented with cardiac catheterization data in the form of traces of relevant variables during one cardiac cycle. An example of one "unknown" situation is shown in Fig. 4. The task is to identify the pathophysiology that explains the observed data. Although heart sounds have not been discussed explicitly in class, a trace of heart sounds during one cycle is also presented as part of the unknown data. The only informa-

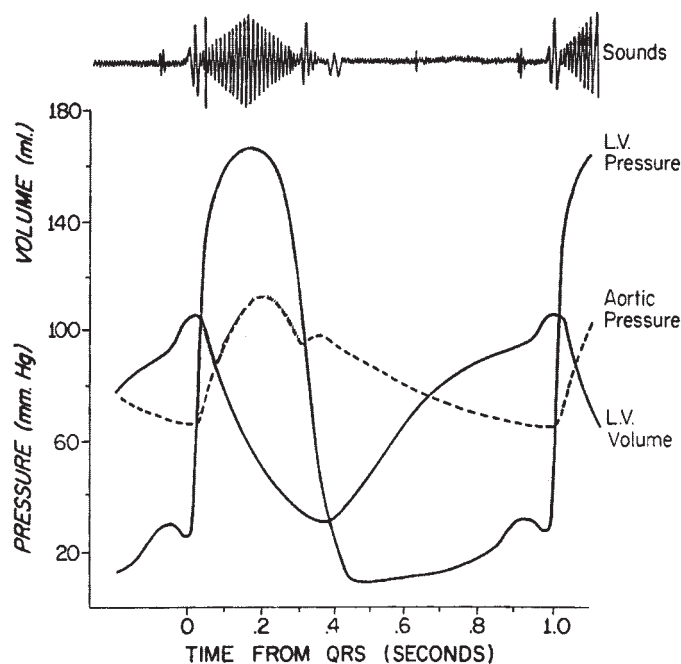


Fig. 4. "Unknown" data provided to students as an assessment exercise following the view from the inside cardiac cycle exercise. LV, left ventricle.

tion given regarding heart sounds is that turbulent flow through a tube creates noise. In general, students are more readily able to correctly identify the pathophysiology of data associated with aortic valve stenosis, mitral valve regurgitation, and mitral valve stenosis following the view from the inside exercise than students presented with the same problems before this technique was implemented. Furthermore, when explaining the basis for their conclusions, students are more likely to discuss their problem-solving strategy in terms of a mechanistic analysis of the traces rather than a comparison of the traces with the normal Wiggers diagram.

In another example, students who have applied the view from the inside technique to the countercurrent multiplier mechanism in the loop of Henle easily make correct predictions of what will happen to the intramedullary concentration gradient when elements of the mechanism are perturbed (e.g., partial inhibition of the sodium-potassium-2 chloride transporter in the thick ascending limb, increased passive permeability to sodium in the thick ascending limb, and changes in glomerular filtration rate).

Since implementing the technique, we have also noted qualitative behavioral changes that suggest that the students are modifying their learning strategies for making sense of physiological mechanisms as well as developing learning strategies for making sense of other disciplines and adopting strategies that lead to better problem-solving skills.

Applications of general models. In physiology, students begin to recognize the applications of general models more readily. For example, when dealing with situations in which flow is being examined, students tend to ask the same questions regardless of the specifics of the system being addressed, for example, "What flow is coming to me? What flow is going away from me? What forces are causing the movement?" After applying the technique to study systemic capillary exchange and edema formation, students readily recognize that filtration

at the glomerular capillary involves the same forces. Before using this approach, students were more apt to view these situations as very different because illustrations of the respective capillary beds look different. Capillaries in a muscle bed are depicted as a tube, and glomerular capillaries are depicted as a tuft of vessels. In these cases, the view from the outside may lead students to conclude that, because the geometry of the vascular bed is different, the mechanisms responsible for fluid movement across the vessel wall are different.

Similarly, when discussing mass balance relationships in a steady state at various locations, students seem more apt to make correct predictions concerning the implications of changes in concentration of a substance of interest at that location. For example, they recognize the parallels between interpreting changes in alveolar CO_2 tension as reflecting changes in alveolar ventilation and changes in plasma creatinine concentration as reflecting changes in the glomerular filtration rate.

Changes in the way in which students interact in small-group discussions. Monitoring small student discussion groups following several experiences with the technique reveals that students are more concerned with the perspective taken by colleagues during the discussion. They will often ask colleagues where they are "standing" when drawing their conclusions.

Transference of the technique to other disciplines. Many of our first-year medical students whose curriculum includes concurrent registration in anatomy and biochemistry reported that they began to use the technique in these subjects. They report that standing "within" a chemical reaction helps them gain perspective on what is happening in the reaction. Similarly, "standing" between two muscles helps them gain more insight into the structural-functional relationships of the muscles. Figure 5 shows an unsolicited email sent to the author by a first-year medical student describing her experience late in the first quarter of the curriculum. Receipt of similar reports from other first-year students and students who have moved on in the curriculum to other courses is a common occurrence.

Adoption of the technique as a general problem-solving strategy. Students encountered later in their medical education and after graduation report that, as a result of their experience in physiology, they often ask themselves, "Where am I standing? What is coming to me? What is going away from me? What is going on around me?" when they encounter problems related to difficult clinical cases.

Discussion

The view from the inside could be considered to be a variation of role playing, a technique that has been used in many disciplines to help students gain a better appreciation for factors contributing to a situation (e.g., behavior in psychology, a political position in political science, and conflict resolution in psychology, sociology, and business). In physiology, role plays are often designed to help students visualize the sequence of events of a mechanism (e.g., Ref. 3). A significant difference between this approach and role plays of physiological mechanisms is that in the traditional role play, students become actors in the process, assuming the function of specific components in the mechanism. In this approach, the student is not a participant

You told us that the techniques you are teaching us would sneak up on us – we'd find ourselves using them without realizing it. You're right and it's downright scary!

1) I awoke from a nap last week wondering how on earth I was to learn "everything" we are expected to know for gross anatomy. My levator scapulae had seized. I found myself wondering, "Where exactly does that muscle attach/insert?" Next thing I know, I was "standing" inside my body on my scapula. "So, if I pull from here, what happens? What do I see? What if I pull from over here?" A light bulb came on, this might be the answer to learning the rest of those origins and insertions since I don't enjoy memorizing tables of information.

2) I went to bed "early" Wed because the biochem wasn't entering my brain. I set the alarm for early the next morning so I could study then. However, I managed to turn off 2 alarms and sleep an extra hour....not nearly enough time left to study what I needed to. Nevertheless, I had earlier drawn out the various reaction diagrams (flow/causal diagrams) and reviewed them several times. During the exam, I found myself going to those diagrams and literally looking around. Was I in the right diagram (model) or did I need a different one? How did I know? What did I see around me? Was the answer obvious or were there clues that would get me closer? In the end, when I chose an answer, I usually had a good reason for choosing it – one that made sense to me. I don't expect that exam was one of my more stellar performances, but the technique of going INTO the model really helped.

Fig. 5. Contents of an unsolicited email from a first-year medical student near the end of the Fall quarter of the first-year curriculum.

in the process. S/he is an observer, reporting and interpreting events in the process to determine causal relationships. By only reporting events, the tendency to anthropomorphize the mechanism is reduced, and the underlying physical and chemical principles governing interactions among components become easier to analyze.

It is well recognized that traditional classroom techniques are not effective in helping students correct misconceptions in science (2, 12). To effect such change, it is necessary for students to recognize the limitations of their mental models (1, 12). The power of this technique becomes evident when it is used to help students recognize conceptual or reasoning difficulties (misconceptions) and the need to modify their mental model of a mechanism. Consider, for example, the misconception discussed earlier regarding the cardiac cycle. In the cardiac cycle exercise, the student considers events in the atrium, ventricle, and aorta just prior to the P wave. At this point, the ventricular muscle is relaxed, and the atrial muscle has not yet contracted. The reporter in the ventricle reports that the pressure is very low. If the student believes that flow from the atrium to the ventricle only occurs when the atrium contracts, and the P wave has not yet occurred, what is keeping the atrioventricular valve closed? What does the reporter in the atrium report at this time? Is flow into the atrium continuing? If so, what is happening to the pressure in the atrium relative to the ventricle? What causes cardiac valves to open and close?

When faced with these questions, viewing the system from within the ventricle, students quickly recognize that flow must occur from the atrium to the ventricle whenever pressure in the atrium exceeds pressure in the ventricle, and, since this occurs well before atrial contraction, the valve must be open during the major portion of diastole. They also recognize that as the ventricle fills, the gradient causing the flow decreases because of the recoil of the ventricular walls. This becomes important to the student in later discussions when ventricular filling (preload) is related to the strength of contraction.

The view from the inside approach can also help students develop strategies for engaging in meaningful learning. We use term "meaningful learning" to refer to a learning process that results in the student being able to use the information being acquired to solve problems (5, 6). The process involves building, testing, and refining mental models (6) and begins with the student recognizing that s/he has prior knowledge (a mental model) that is relevant to the topic at hand. The task, then, is to make this mental model visible and use it to develop expectations (make predictions) about the mechanisms to be studied. The next step is to test those predictions by gaining new information about the system and modify the mental model to account for discrepancies between the predicted and actual behaviors of the system.

The utility of the view from the inside in this process can be illustrated by considering an exercise used during a study of gastrointestinal physiology and designed to establish expectations for mechanisms that control the environment in the duodenum. The student is directed to "stand" at a viewpoint in the duodenum. The view includes the pyloric sphincter and the sphincter of the hepatopancreatic ampulla (sphincter of Oddi). The task is to predict, based on current knowledge of digestion and absorption of dietary substrates in the small intestine, how the system will respond to entering chyme from the stomach. What might sensors in the duodenum detect? What actions might occur as a result of this detection? Where might substances entering through the sphincter of the hepatopancreatic ampulla originate? What mechanical action might occur in the small intestine, and how might these actions be controlled? How might chyme entering the duodenum influence gastric function?

The limited view at the viewpoint encourages the student to think about chemoreceptors causing hormone release and/or reflexes involving the enteric nervous system, mechanical mixing of duodenal contents to promote enzyme substrate interaction (from emulsification and increased surface area), movement to the luminal epithelium for absorption, etc.

Final Comments

In our experience with this technique, it is clear that the view from the inside helps students establish an appropriate frame of reference for examining a variety of mechanisms with a variety of complexities, and it helps them make sense of physiological mechanisms. However, the technique may also be valuable in another realm: diagnostic problem solving.

When helping students learn to problem solve, we often tell them to start at the problem and work “outward” to determine the causal relationships responsible for the pathophysiology. An example that we might use to illustrate the point is an automobile accident. The first question to be asked when encountering an automobile accident is: “What happened?” The answer that one car ran a red light provides more information about the immediate cause than the fact that the driver was drunk. Similarly, when confronted with a pathophysiological situation (e.g., left ventricular failure), the first step is to ask: “What could cause the ventricle to fail?” Many students, however, choose to take a more global view: “His heart failed because of an unhealthy living style.” Using the view from the inside approach could help these students focus on a more appropriate frame of reference from which to approach the problem.

The simple question “Where are you standing?” is a powerful vehicle for approaching meaningful learning over a broad spectrum of disciplines. Helping our students recognize this

fact may help them develop the necessary learning strategies for success in the integrative pursuit of science.

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