Evolution of an educator: lessons learned and challenges ahead

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In selecting a Claude Bernard Distinguished Lecturer, the Teaching Section looks for an individual who has made major contributions to physiology education. Dr. Harold Modell has certainly earned this honor. Harold has an undergraduate degree from the University of Minnesota, a Masters in biomedical engineering from Iowa State, and, continuing the southern migration, a Ph.D. from the University of Mississippi Medical Center. After four years in Buffalo, first as a postdoctoral fellow and then as an assistant professor, Harold made the long trek to Seattle, WA, where he has been ever since. Harold Modell’s contributions to physiology education are many and varied. He was certainly one of the early developers of teaching software aimed at helping students learn physiology. His programs are widely used, but more importantly, he has been instrumental in bringing others into the field of computer-based education. The existence of the Teaching Section is in no small measure the result of Harold’s efforts to persuade APS that teaching was important to a great many of its members, and to the Society. Similarly, this journal, Advances in Physiology Education, came to life after a long campaign spearheaded by Harold. As the journal’s founding editor, he set the stage for the growing success that it is enjoying today. Finally, Harold is an educational researcher of note whose every project is aimed at helping the learner to learn. As a leading advocate of this attitude, Harold has helped physiology teachers at all levels adopt this approach to teaching.

active learning; physiology education; learning environment; meaningful learning

CHAPTER 1: THE JOURNEY BEGINS

Our story begins in the late 1960s. We’ll call our main character Harold (although there are some who would prefer that we call him Howard). At his point in time, our future educator was a graduate student in a physiology department in which the degree requirements included building a computer model of the problem that was the focus of his laboratory research. He chose to develop a computer simulation of the pulmonary circulation.

One day, Dr. Sol Permutt, the investigator who did a good deal of the laboratory research on which the simulation was based and one of the young graduate student’s heroes in physiology, visited the Department. Harold had an opportunity to discuss his model with him. As he began to explain his model, Dr. Permutt told Harold to stop and start at the beginning. Dr. Permutt needed more background before he could discuss the workings of the model. Perplexed by this, our graduate student said something like, “But you did the work on which this is based!” Dr. Permutt’s response was a big surprise to Harold. He said that he had done the work some time ago, and he just didn’t remember all the details of everything that he had done. He needed reminding!

During his early career, Harold had opportunities to meet, watch, and interact with other people that he considered “great thinkers” in physiology--people like Arthur Guyton, Hermann Rahn, Walter Randall, Leon Farhi, and others who were leaders in other areas of physiology. He was impressed that essentially all of these people were not afraid to say, in public...
forums as well as in private conversations, “I’m sorry, I don’t follow you,” or “That doesn’t make sense to me.”

To many people, these statements were admissions of ignorance. You wouldn’t find very many students who would admit to not understanding something in a public forum like a classroom. It just isn’t done. You don’t want people to know what you don’t know. Yet these great scientists, great thinkers, were not afraid to admit that they didn’t know something or that something didn’t make sense to them.

The lesson that our future educator learned from these people is that a willingness to admit to not knowing something is not a weakness, as many of our students believe. It is a strength. If you don’t admit that you don’t know something, you have a difficult time engaging in meaningful learning.

Lesson 1: Willingness to admit to not knowing something is not a weakness. It is a strength.

One lesson we should try to impress on our students is that admitting to not knowing something and seeking clarification is an important step to learning.

CHAPTER 2: THE ROAD TO ACTIVE LEARNING

Our story continues several years later, when our young physiologist was a postdoctoral fellow at the State University of New York at Buffalo. This newly graduated Ph.D. arrived on the scene expounding the glories of computer simulations as thinking tools. The computer simulation, he learned from Dr. Guyton, gave mediocre thinkers like himself a tool to discover new connections among components of complex systems. He learned that, by taking one step at a time and seeing where that step led, he was able to think about complex problems and systems in ways that he had never been able to do previously. Certainly, if he benefitted from this practice, imagine what other people who were far brighter than he could do! Everyone must be told of the benefits of such techniques!

Although his enthusiasm didn’t bring many converts to the legions of computer modelers, it did prompt Dr. Hermann Rahn or Dr. Leon Farhi, or maybe both (the record is not clear), to ask Harold, “If this works so well for you, do you think it would help the medical students learn respiration?” And so, Harold, along with Drs. Albert Olszewka, Leon Farhi, and Robert Klocke embarked on a project that resulted in a series of computer simulations dealing with various aspects of the respiratory system. The idea was to provide students with a tool to begin examining the system from a relatively “simple” view and, in a stepwise fashion, add complexity. For example, the gas exchange set of models dealt first with a single-compartment lung that exchanged gas with the atmosphere, and then a vascular component was added to examine oxygen and carbon dioxide transport by the blood. Next was added a lumped tissue bed to examine exchange between the atmosphere and tissues. A provision for anatomic shunt was then added, and then a provision that allowed students to examine the concept of matching of ventilation and perfusion. The final model in this series was a two-compartment lung with the possibility of anatomic shunt flow coupled with a circulation and a lumped tissue bed. The programs were first released in 1975 [Modell et al. (5)], and the current version, designed for use in a Windows environment, is still available as freeware from the Physiology Educational Research Consortium website (www.physiologyeducation.org).

What lessons were learned from this project? The first lesson was that, given the tools and the opportunity to solve problems, students could engage the material in a way that would help them build models with which they could think about complex physiological systems.

Lesson 2: Given the opportunity to engage concepts and use key principles to solve problems or make predictions about the system, students can build robust models of physiological systems successfully.

The process that they went through has come to be called “active learning.” It is a process by which students test and refine their ideas of the ways in which components of a potentially complex system interact. It also provided a means by which students, in Dr. Farhi’s words, “could reason from basic facts to general principles.” [Modell et al. (4)]. However, without engaging these concepts and key principles, students are not likely to build robust models of physiological systems.

CHAPTER 3: THE “ACCEPTABLE” JOB

At this point in our story, we find that our future educator moved from Buffalo, NY, to Seattle, WA. He became a member of the Physiology and Biophysics Department at the University of Washington. In this capacity, he took on teaching responsibilities as well as establishing a research lab in respiratory physiology. When asked about future goals, he would reply that the ideal job would be somewhere where he could do bench research half-time and educational research and development half-time. Colleagues responded to this goal statement by saying that Harold would like to do research half-time and teach half-time, but that was not what he had said. He was interested in doing respiratory physiology research and research and development intended to provide students with better opportunities to learn.

During this time, he published several papers describing approaches that he was taking toward his teaching efforts. He believed that his educational endeavors should share the same characteristics as his science efforts: they should be potentially fundable; they should be peer reviewable; and they should be publishable. Not adhering to these principles would mean not fulfilling his obligation to his profession.

Several years after arriving in Seattle, Harold had an opportunity to move his lab to the Virginia Mason Research Center, a private research institute. A significant concern that faced our young physiologist was how he would be viewed by the physiology community if he no longer had an appointment in a physiology department. Despite this concern, he moved the lab. He still had a University appointment, now in the Departments of Radiology and Internal Medicine. He still taught in the same medical school courses; he continued his bench research; and he pursued his interests in educational research and development. One day, he received a call from Orr Reynolds, then Executive Secretary of the American Physiological Society (APS). Orr wanted to know if Harold was interested in serving on the Education Committee of the APS. The APS didn’t seem to care that he was not a member of a physiology department. They seemed to be more interested in the work that he was doing rather than where he lived.

The lesson learned was that the acceptable job is the job that lets you pursue your “path” and pays you to do it. The unspoken message that graduate students received at the time,
that the “acceptable” job was in a physiology department at a major medical school, was wrong!

Lesson 3: Follow your “path.” Look for an employer that will let you follow your path. Do good work.

If the job that allowed you to pursue your goals was at a community college, it was a good job and one in which you could make a positive difference in the lives of your students. The key is not where you do your work, but what kind of work you do and whether or not you fulfill the obligation of sharing the results of that work with your discipline in a peer-reviewed manner.

A book describing the history of the American Physiological Society, published in honor of the Society’s centennial [Brobeck et al. (1)], records that our hero was instrumental in forming the Teaching Section of the APS, and the first issue of Advances in Physiology Education, published in June, 1989, lists Harold as the editor. Not bad for someone who lived in a private research institution and later in a department of radiology!

Again, the lesson learned was that, if you do good work and meet your obligation to share that work with colleagues in your discipline, the title of the department or the size of the institution in which you live is not important.

CHAPTER 4: AND ALL THAT JAZZ

Although this is an important lesson to learn, it does not help us gain insight into Harold’s development as an educator. So, let us return to that part of our story. You’ll remember that, as a result of the computer simulation experience, Harold became interested in exploring ways to promote active learning in the classroom. His thinking about how to accomplish this took an interesting turn in the spring of 1979.

Our young faculty member read in the newspaper that the Music Department at Edmonds Community College, one of the Seattle area community colleges, was having a jazz festival and that the featured artist was going to be one of Harold’s favorite vocalists. This was a concert he must attend!

On the evening of the concert, he and Jane arrived at the gymnasium at Edmonds Community College and found what they considered suitable seats from among the card table chairs set up for the audience. At about 8:20—the concert was supposed to start at 8:00—16 singers and a three-piece rhythm section came to the stage. All were 17 to 19 years old and students at the college. The group was introduced as Soundsation ’79 under the direction of Mr. Frank DeMiero.

Soundsation began its first number, and Harold could not believe what he was hearing.

Here was a group of community college students that performed as if they had been working together for years rather than the few short months since the school year had begun. Their enthusiasm was infectious, their timing was incredible, and their musicianship was excellent. This group could compete with any professional vocal group that he had ever heard!

After the initial shock, Harold started to think about how this DeMiero fellow could get his students to accomplish so much in six short months. The answer, of course, was that his classroom was an active-learning environment. Music was one of the few subjects that required students to be engaged in active learning. The only way to become proficient at performing was to perform!

As the performance continued, Harold became even more impressed and began saying to himself, “Self, I’ve got to meet this Frank DeMiero and spend time in his classroom. There is obviously much to be learned from him about promoting an active-learning environment.” And indeed there was!

Well, the two met, and Harold spent time in Frank’s classroom, at his concerts, and at his jazz camps. Frank spent time in Harold’s classroom, and the two engaged in many conversations about education over the next 20-plus years. In addition to hearing a lot of great music, Harold learned much about what it meant to be an educator.

When dealing with students, Frank created an environment that was safe and supportive. It was a positive atmosphere in which students were encouraged to take musical risks and allowed to make mistakes. What was amazing to watch was the way that students responded to what Frank did. It didn’t seem to matter whether the encounter was a one-time event for 20 minutes or a multiyear teacher-student collaboration. This man was able to draw the best from his students.

What was his secret? First, he let his students know that he was human, too, and that they were all part of a learning community, a community in which each individual’s effort was important to the success of the group and in which each member of the group was treated with respect. It was the responsibility of each member to do his or her own work and to provide encouragement and support to the rest of the group. He also conveyed a feeling to his students that he cared about their well-being and their development as a person, not just as a singer in the group. In many ways, each class developed a feeling of family in which they could feel safe and nourished in terms of their learning. In this environment, the students worked hard and had fun, both with their music and with their classmates.

What lessons were learned from visiting Frank’s classroom? First, that the “teacher” should be a mentor, not just a source of information. As a mentor, the teacher must show respect for and convey a sense of caring to his or her students. Through his or her interaction with students, the teacher must give permission to the student to make mistakes and provide encouragement when mistakes are made. Of utmost importance, the teacher must create an environment that reassures the student that he or she is not alone in the learning endeavor.

Lesson 4: The teacher should be a mentor, not just a source of information. The teacher must create an environment that reassures the student that he or she is not alone in the learning endeavor.

CHAPTER 5: THE EPHEMERY

Before continuing our story of the evolution of our physiology educator, it may be helpful to know a little bit about his childhood. Harold grew up in the golden age of television. As a result, he did not read many books. He was convinced that anything that was important to know would eventually appear on television, and through this medium he would learn about it.

You can imagine how an experience that he had in 1995 profoundly affected his life. Harold read a book! The book was entitled, Freedom to Learn [Rogers and Freiberg (6)]. It was an update of an earlier Carl Rogers book written by Jerome Freiberg. Harold had met Freiberg that year at the annual meeting of the American Educational Research Association.
Jerry had experience with student populations ranging from the sixth grade to the college level. His insights were applicable to all of these populations, and they ultimately formed one of the cornerstones of Harold’s development as an educator.

The message of Freedom to Learn was that it is the student’s responsibility to learn. What a revolutionary thought! The teacher cannot learn for students: students must do that for themselves! However, the student must be given the freedom to take responsibility for his or her learning.

Lesson 5: Students must take responsibility for their learning. Students must be given the freedom to take responsibility for their learning.

If there was an epiphany that was key to Harold’s becoming an educator, this was it. Imagine! The student must take responsibility for his or her learning! So, if it’s up to the student to learn, what is the instructor’s job? Is it just to provide the student with information? That is what happens in most classrooms. No, if it’s the students job to learn, it is the instructor’s job to help the learner to learn. Harold began to think about what this really meant. First and foremost, it meant that teaching was not about the teacher at all! It was all about the learner! It meant that the teacher should not ask, “How should I present this?” Instead, the teacher should ask, “What does the learner need to learn this, and how can I help the learner accomplish this goal?”

Harold no longer told people that he taught physiology. He told people that his job was to help the learner to learn. His view of the classroom changed, and his view of what he did in the classroom changed. If his job was to help the learner to learn, he had to find out more about his students. He had to think about how they learned. He had to find out about what they were thinking. He had to find out about how they were interpreting what was being said in the classroom. He had to find out how they were putting their thoughts together. In short, he had to interact with his students on a continual basis. It was only through interaction that he could gain insights into the problems that his students were having when learning to think about physiological systems. His role in the classroom changed from being a purveyor of information to being a clinician who diagnosed problems that his students were having in the learning process and helped them address these problems.

The mantra “helping the learner to learn” truly helped focus Harold’s motivation and direction as an educator. Issues related to the learner and the process of learning became pivotal in directing his research and his classroom activities. Seeking ways of promoting an active-learning environment was no longer an issue because, if his job was to help the learner to learn, he had no choice but to help students actively engage in the learning process. Furthermore, he didn’t have to discard all of his past resource material and start over. The students’ needs would point the way in which the resources should be used.

Freedom to Learn had opened new vistas for exploration. It provided the final step in the evolution from physiologist to physiology educator. Harold began to think about what it meant to engage in meaningful learning and how to help students engage in meaningful learning. He began to think more about what must go on in the classroom if the instructor is to be successful in helping the learner to learn. But, that’s jumping too far ahead in our story.

CHAPTER 6: ANOTHER BOOK READ

After having the life-changing experience that came from reading Freedom to Learn, our now physiology educator took a considerable risk. He read another book! This book was called Learning to Listen—Learning to Teach, written by Jane Vella (7). Although the educational settings in this book are not the traditional classrooms that we are most used to, the messages in the book are certainly germane to helping the learner to learn in any setting. In this book, Vella recounts a number of experiences that she had while leading community education and staff development programs. These were generally workshop environments of several weeks’ duration.

There were many lessons to be learned from the book, but Harold was most impressed by two. One chapter of this book is devoted to a discussion of creating a safe learning environment.

Although most instructors would agree that creating a safe learning environment is important to students’ learning, few think seriously about how to foster safety in the classroom. Vella’s discussion of this topic helped Harold recognize how critical a feeling of safety is to the success of all aspects of classroom activities and how many factors contribute to this feeling. When he reflected on Frank DeMiero’s classroom, the safety of the environment was the underpinning of all of the positive outcomes that Frank was able to achieve.

Lesson 6: Students must feel safe in the learning environment.

The second lesson had to do with helping learners recognize that they, in fact, had learned.

Recall that Vella’s students were attendees at workshops. There were no examinations as there are in a classroom environment. Her challenge was convincing workshop attendees that they had learned and could perform the tasks that were dealt with in the workshop. Her solution was simple. The way you help the students recognize that they can accomplish the tasks is to have them do the tasks! This sounds very simplistic, but it is something that eludes many classroom teachers. In physiology, our goal is to have our students be able to solve physiological problems. Unfortunately, many instructors don’t ask students to solve problems until the exam, if then. Vella’s message is that, if you want students to be able to do something, you must provide an opportunity for the students to do that thing! Opportunities for practice must be included in class activities.

Lesson 7: If you want students to be able to do something, you must provide opportunities for them to practice doing it.

CHAPTER 7: HOW DOES IT ALL FIT?

So far, our story has highlighted about a half-dozen lessons learned that all seem to be common sense:

• Certainly, one can’t learn if he or she is not willing to admit to not knowing something.
• Experiences in our everyday lives confirms that we cannot engage in meaningful learning, that is, applying information to accomplish a goal, by only hearing or reading about the information. We learn to apply information by using it. So, if we expect to solve problems, we must be actively engaged in the process of solving problems!
• It makes sense, if you want to be happy, to follow your path, and seek a working environment that will allow you to do that.
• It also makes sense that the most learning will occur in a safe, supportive environment in which the student is encouraged to try new things.
• And what about the notion that the student is responsible for his or her learning? Well, who else could be responsible? Mr. Spock has not made the Vulcan mind meld available to us, and, in this age of technological miracles, we have not discovered any other techniques to put well-developed thoughts directly into somebody’s head. So, the student must be responsible for his or her learning!
• Finally, we come to Jane Vella’s lessons of creating a safe environment and helping students gain confidence in their ability to accomplish a goal by having them practice the steps to reach that goal. This all makes good sense to me.

If I were listening to this story, I would ask the storyteller, “What’s the point of all this? Knowing some common-sense lessons that our educator learned along the way doesn’t really help me gain insight into his being an educator. I am more interested in how he applied these lessons in his pursuit of helping the learner to learn.”

So, let’s refocus our story on Harold’s journey as a physiology educator. We can begin this part of the story in 1989, when he made the decision to give up bench science research and focus his activities on educational pursuits full time. Because funding for the type of educational projects that he was interested in doing was not available in the medical school environment, he gave up his full-time appointment at the University of Washington School of Medicine and started a small business aimed at educational research and development.

This led to a National Institutes of Health Small Business Innovative Research grant to develop a series of educational computer simulations in renal physiology. As part of this project, he began to establish collaborative ties with other physiologists who were interested in improving physiology education. This group served as the foundation for the Physiology Educational Research Consortium, a 501(c)(3) nonprofit organization that we affectionately call PERC.

Three years later, Harold reestablished major contact with a student population. He became responsible for the year-long physiology course at Bastyr University, a naturopathic medical school in Seattle. This provided, and continues to provide, a means of interacting with a population of medical students in a learning environment of his design. Because he works with these students for a full academic year, he is able to learn about the ways in which these students approach their learning, the academic challenges they face in their learning, the personal challenges that impact their learning, and the problems that they have making sense of physiological mechanisms. This interaction provides new challenges and insights into Harold’s quest to help the learner to learn, and it provides research ideas for PERC. Every day provides new experiences in the classroom with a group of students who are willing to share and grow together.

Assuming responsibility for the physiology curriculum at Bastyr represented a new challenge for our physiology educator. How should he go about designing this course? Where should he start?

Many people would start with the question, “What should the students know at the end of the course?” But, on the basis of the lessons that he had learned, this was not the appropriate starting point. Most physiologists will tell you that they want their students to be able to solve physiological problems. That is, they don’t want their students merely to acquire facts about physiology; they want students to be able put these facts into a series of models that they can use as thinking tools to solve physiological problems. The goal is to use information rather than have information. This is what we call meaningful learning, or learning with understanding, in the education realm.

Using the lesson from music education, Harold’s first step (Fig. 1) was to define the performance goals that he wanted his students to reach. Recognizing that his job was to help the learner to learn, his next step was to get some idea of what he called the input state of the students. What was their background? What knowledge and skills did they have? With this information, he could design learning experiences that could help the students reach the performance goals. But, in order to be successful in this endeavor, he recognized that this process was only the beginning.

He had to establish a learning environment in which students were free to take responsibility for their learning, an environment in which they felt safe in taking the risk of admitting to not knowing something or proposing mechanisms or making predictions that were wrong. There is not time in this forum to discuss the steps that he took to creating this environment, but these are discussed in a book that he and Joel Michael published recently [Michael and Modell (2)].

What we can do in this forum, however, is review some critical questions that Harold faced in this process. For example, was his job to help the learner to learn physiology or was

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Fig. 1. Steps to designing a course or any classroom activity.
his job to help the learner to learn? He decided that it was the latter, which meant that, in addition to dealing with physiology content, he had to help his students become aware of and reflect on how they learned. What steps does one go through to engage in meaningful learning? How do the kinds of activities that make up the course help the learning process? Thinking about the learning process became a critical part of his course. A second question was, “How do I approach the classroom?”

On the basis of the lessons learned from visiting Frank De-Miero’s classrooms, and reading Jerry Freiberg and Jane Vel-la’s books, he developed strategies that would lead to a safe environment in which the instructor and students would form a collaborative learning community.

An important component of this strategy was based on his past experience as a bench science researcher. He would approach the classroom in the same way as he had approached his science.

If his job was to help the learner to learn, he had to learn more about his students, and this had to be a continuous process. So, just as he would reflect on the outcome of a science experiment, asking what happened during the experiment and what the data meant, he would have to reflect on what went on in the classroom. Through this reflection, he would, hopefully, gain insights into how to improve classroom prac-tice in the same way that he gained insight into the mechanisms that he addressed in the science laboratory.

Through this practice of interacting with students and being a reflective practitioner, Harold’s classroom environment continues to improve, as does his insights into the problems that students have engaging in meaningful learning and the challenges facing physiology education in general.

Shortly after beginning at Bastyr, Harold had a new experience, which continues some 10 or 12 years later. He began getting thank-you notes from students at the end of the year and as they continued on in their medical education. Below is a sampling of some of these students’ comments that provide a better idea of the experiences that the students have had.

- I already thanked you after Physiology, but here I go again. I got more out of your class than you could imagine. My grades may not reflect this, but old habits die hard. I think about the lessons from class daily. Thanks for one of the best learning experiences I’ve had in my life. Your presence at Bastyr is a gift!
- I want to thank you so much for everything you have done for our class. You have taught me so much . . . a different way of thinking and a different way of learning. And although it has been frustrating at times, this new way has changed my approach to learning. In my years as a student, I’ve met only a few instructors who care so much about their students’ education . . . you definitely are one of them. Your efforts and hard work are much appreciated.
- I just wanted to let you know that this past year has been a journey and you have helped me along my way. I truly feel I have learned a lot, and not just academically speaking. Thank you for sharing your love of music with us. Despite the pains and frustrations felt throughout the year, I can appreciate what you have helped me attain.

From a student after she received her ND degree:
- I just wanted to let you know how much I value and appreciate you for the part you played in helping me earn my degree. I feel that you are an excellent teacher and I know how committed you are to your students (certainly not many teachers are as committed as you.) Thank you for everything you do for the students. You are highly appreciated.

Finally, from a student who left the university for other pursuits:
- I decided to leave Bastyr, but I just wanted to write to you to thank you for always having the time for me and for all you taught me, not only physiology and neuroscience, but in life and what matters.

When Harold received the first thank-you card from a class, he called Joel Michael and asked if the card could be counted as data, and if it was publishable.

CHAPTER 8: A LOOK INTO THE FUTURE

We have come to end of our story about Harold’s evolution from physiologist to physiology educator. We have not, how- ever, come to the end of the story. The evolutionary process continues. The characteristics of the student population continue to change; the culture in which we live continues to change; physiology continues to change; all manner of things that impact our students’ learning continue to change. As a result, the classroom environment continues to change, and challenges to improving that environment continue to emerge.

Some of these challenges are related to our students, and some involve our role as facilitators of learning. For example, remember the lesson about students taking responsibility for their learning? At the beginning of the Bastyr Physiology course, the fact that the students must take responsibility for their learning is discussed. The students agree and readily voice acceptance of that responsibility. But do the students understand what “taking responsibility for your learning” really means? I would argue that, at least at the beginning of the course, very few do.

When students say that they accept responsibility for their learning, they’re thinking of their past experiences in the classroom. They accept responsibility for coming to class to write down what the instructor tells them. They accept responsi-bility for going home and memorizing what they have been told, and they accept responsibility for being able to tell the instructor on an exam what they have been told in class. Some accept responsibility for looking for more information when they don’t think they understand something said in class.

Certainly, the willingness of good students to accept responsi-bility for their learning is there, but, because they have not had much experience in the classroom with the type of learning that allows them to apply their mental models to solving problems, they are not prepared to accept responsibility for the process that is consistent with meaningful learning and being a life-long learner. When faced with a problem to be solved in their everyday lives, they don’t generally go to someone and say, “Show me how to solve this problem so that I can go and solve the next one.” No, they recognize that they have some ideas about the problem; they try to solve the problem and find out if their ideas are correct. If they aren’t, they gather more information, change their ideas, and try to solve the problem again. In our terms, they make their mental models visible to...
themselves, they test their mental models, and, on the basis of success or failure of the test, they refine their mental models. These are the steps in the learning process that is necessary to become a life long leaner.

**Steps to meaningful learning:**

- Recognizing an existing mental model
- Testing the mental model
- Refining the mental model

We must help students recognize that accepting responsibility for their own learning means that they prepare for class by previewing material and thinking about what that material means to them. It means coming to class with questions in mind to be answered, and it means participating in class discussion aimed at using that information. We must find ways to help them adopt learning strategies that they can use to engage in meaningful learning as they make the transition to life-long learners. Some of our current research efforts at PERC are aimed at addressing this challenge.

If we expect students to engage in meaningful learning, don’t we have to adopt a process that will encourage meaningful learning in our classroom environments? Of course, and so another challenge is to help faculty recognize some of the lessons that we have talked about this afternoon. We must help faculty recognize that their job is to help the learner to learn and all that this job description entails. To help meet this challenge, PERC instituted a faculty development program a number of years ago that has included partial-day workshops at national meetings, full-day or multiday invited workshops at various institutions, and multiday short courses that are part of the National Science Foundation-sponsored Chautauqua Short Course program. We have also addressed these issues in a book designed to encourage the reader to reflect on the notion of helping the learner to learn (2). The book also presents examples of approaches to applying this mind-set in the classroom.

These challenges are relevant to situations that involve students and instructors in any discipline. As physiologists concerned about the teaching and learning of physiology, we are faced with some additional challenges that are discipline specific. Physiology is included in science curricula ranging from the high school level to the medical and graduate school levels. Physiology is about mechanisms, and physiologists will tell you that the goal of learning about physiology should be to use that information about mechanisms to gain insights into physiological problems ranging from personal health issues to furthering our knowledge about physiological systems. The extent to which this goal is reached at any level depends, in large part, on two things: how well the instructor understands the mechanisms to be learned and the ability of the instructor to help the learner build appropriate models of these mechanisms for themselves.

Unfortunately, many faculty responsible for physiology courses, especially at the entry levels, do not have formal training in physiology. As a result, they rely on the texts and other learning resources that they choose to provide them with the necessary information to teach their students. The problem is that most physiology texts, especially at the introductory levels, are descriptive in their presentations. They are not mechanistic. They tell what happens without telling how things happen. As a result, students are not able to build the causal links that are necessary if one is to solve problems at any level, and faculty are often not prepared to help them build these links. We must encourage textbook writers and developers of learning resources to provide materials that are consistent with the fundamental principles of our discipline. If we expect students to be able to use information, we must provide that information in ways that lend themselves to application. In addition, we must do a better job of helping physiology teachers gain insights into the common themes, what we call general models, that form the foundation of physiological mechanisms [Modell, (3)].

On the other end of the spectrum, we have instructors who are experts in physiology. They have a good understanding of physiology mechanisms and, depending on their graduate program, how these mechanisms interact to determine systemic integrative function. What they often don’t have, however, is a clear understanding of how to help the learner to learn these mechanisms. Faculty don’t often reflect on the knowledge and skills base of their students. They don’t reflect on the challenges that they faced all those years ago when, as students, they tried to make sense of the mechanisms. This lack of what in the education world is called pedagogical content knowledge, exists at all levels of instruction. Just as we need to do a better job of helping instructors with little formal training in physiology to learn about physiological mechanisms, so, too, must we help instructors who know about physiological mechanisms to become more aware of the problems encountered by students who are trying to learn physiology and ways of addressing these problems.

The journey continues, and it continues to take twists and turns that lead to new insights and exciting challenges. It certainly keeps our educator young. I encourage all of you who deal with students to reflect on how you approach your classroom and your interaction with students.

Remember, it’s not just about students getting information; it’s about process. The process of putting information together in ways that let the learner use the information to solve problems. It’s all about the learner! The learner must do the work. The best you can do is to help your students recognize what they must do and suggest ways that they might do it.

**REFERENCES**