DEVELOPING EFFECTIVE MENTAL KNOWLEDGE STRUCTURES FOR MEDICAL PHYSICS APPLICATIONS.

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Abstract --- **The performance of many medical physics functions in both medical imaging and radiation oncology require knowledge consisting of mental networks of concepts in addition to the traditional verbal and mathematical representations provided in classroom teaching. The classroom is limited as an effective learning environment because it is separated from the "real world" of clinical physics that is the source for interactive learning. Collaborative teaching is a method used to provide the classroom with enhanced visual access to medical physics applications and enable classroom instructors to guide learners/students in developing higher-level and more effective knowledge structures.**

Keywords --- **Knowledge, Concepts, Learning, Teaching, Collaboration**

I. INTRODUCTION AND OVERVIEW

A significant goal of all medical physics education and training programs is the development of medical physicists who can perform specific functions in the various professional activities including clinical medical physics, risk management, education, and research. That is the process of *effective education*. It is education that prepares for specific and well defined functions or tasks. One of the continuing challenges of medical physics educational programs around the world is that of providing truly effective education, especially to meet the expanding roles of medical physicists relating to the many innovations and developments in both medical imaging and radiation oncology. Our purpose here is not to describe specific educational methods or materials but to focus on the basic characteristics and requirements for learning and teaching activities to produce effective medical physics knowledge. We consider how humans learn and the conditions that contribute to effective learning.

II. PHYSICS KNOWLEDGE

Knowledge of physics is a mental representation of segments of the physical universe in which we live, ranging from sub-atomic particles and interactions to outer space. Medical physics is a specific area or component of this universe. We begin with a general model of medical physics knowledge and the learning process is illustrated in Figure 1.

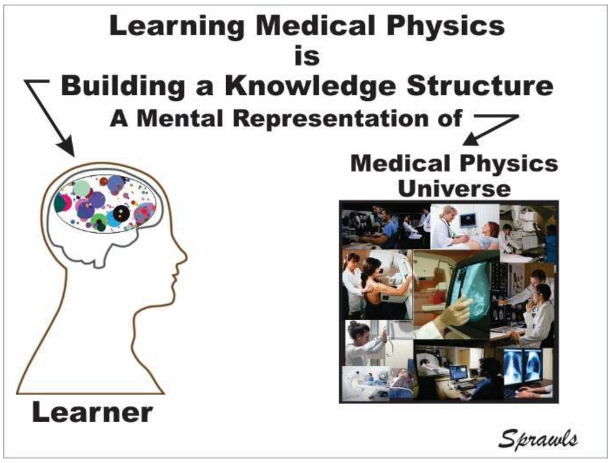

Figure 1. Learning medical physics is a continuing process of building mental representations of a specific area of the physical universe as we study and gain experience.

Each of us has our unique and personal knowledge structure that is determined by our education and interactions with medical physics activities throughout our career. Our specific interest here is the knowledge that enables us to perform specific activities or functions, which is different from general knowledge or just knowing a topic.

We will now consider the general knowledge structure for physics, then the process of learning or building knowledge structures, and conclude with conditions to develop effective medical physics learning activities and knowledge.

Our knowledge structure or mental representation of physics, including medical physics, is composed of three types of elements--sensory concepts, quantitative, and verbal--as illustrated in Figure 2.

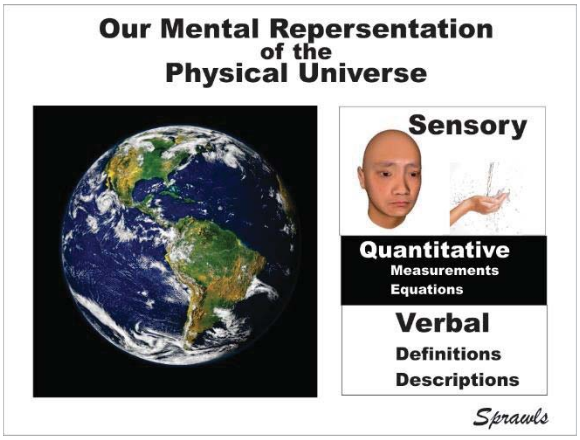

Figure 2. Three types of elements that are components of our knowledge of physics: sensory, quantitative, and verbal.

An effective knowledge of medical physics requires the appropriate combnation of these three elements, depending on the functions or task to be performed. Developing these appropriate knowledge structures is one of the major challenges within medical physics educational programs and activities.

III. EFFECTIVE AND EFFICIENT EDUCATIONAL ACTIVITIES

Every educatonal activity, including classroom lectures, selfstudy with books and online resources, laboratory exercises, and continuing work experience is charactized by two often opposing conditions, *effectiveness* and *efficiency*.

The *effectiveness* of a learning activity determines its ability to produce knowledge structures to enable the learner to perform specific functions that can range from providing verbal definitions on a written examination to performing higher-level analytical and creative activities within the scope of medical physics.

The design, development, and delivery of an effective learning activity requires a clearly defined learning outcome or objective. There must be a match between the knowledge structure and the activity or task to be performed.

The *efficiency* of a learning activity relates to the cost of providing it, including human effort and time, facilities and resources, and much more. A prevailing factor in education is the opposing effects of effectiveness and efficiency. An activity that is effective, especially for higher-level medical physics functions, is generally low in efficiency and requires much more time, effort, and resources to provide.

IV. VERBAL AND LINGUISTIC KNOWLEDGE STRUCTURES

Words and language are the elements forming the major component of our knowledge in virtually all topics. Two valuable characteristics: it can be written or recorded and used for communicating both aural and in script form. In the field of physics language provides a *symbolic representation* of the various areas of the physical universe but not a more direct representation as described later. Language represents the physical universe primarily in terms of verbal descriptions, facts, and definitions. While this form of knowledge is important it has significant limitations in enabling a learner to perform many medical physics activities.

A major issue with physics knowledge consisting of words is that it is *high* in efficiency for teaching but *low* in effectiveness for many medical physics activities. It is relatively easy to teach through lectures and written materials giving verbal descriptions and definitions. It is also easy to test using written examinations.

However, verbal knowledge has major limitations with respect to performing many medical physics activities.

V. QUANTITATIVE AND MATHEMATICAL KNOWLEDGE STRUCTURES

Physics is truly a quantitative science. Every component and element of the physical universe has a quantitative value for which specific names have been assigned along with a variety of units in which quantitative values can be expressed. One example is the *quantity* energy that can be expressed in *units* ranging from electron-volts (eV) to kilowatt-hours (KWH), depending on the specific application. Every area of the physical universe, including medical physics, consists of a dynamic and often complex relationship among many physical quantities. These relationships can be expressed with mathematical equations and several types of visual and graphical representations.

In the field of medical physics a quantitative knowledge (including relationships expressed with equations) is *essential* but not *sufficient* for many functions to be performed, especially in clinical support activities.

VI . PHYSICS EDUCATION

In the broad spectrum of physics education, ranging from introductory to advanced graduate courses, for the most part it is the verbal and quantitative (definitions, facts, equations) representations of the physical universe that are being taught and learned. While this is an essential part of physics knowledge and should be taught, it is with limitations. Compared to some other learning activities to be discussed later, teaching the verbal and quantitative representation is relatively efficient requiring less effort and fewer resources. Most textbooks, classroom lectures and discussions, along with problem solving homework and sessions are the foundation to this form of education. While this is sometimes augmented with illustrations and student laboratory exercises, it does not provide the sensory interaction with the physical universe and the formation of conceptual knowledge that is essential for many medical physics activities.

VII. EXAMINATIONS AND KNOWLEDGE STRUCTURES

Often the desired learning outcome or objective is to perform well on written examinations ranging from "pop" quizzes within a course to professional board certifications. This creates a strong correlation between the design of educational activities and examinations. Verbal and quantitative examinations requiring the recall of facts and solving mathematical problems are relatively easy to develop and score. Examinations within academic courses are always testing on what has been taught, both in content and type of representations. Within the fields of medical physics, technology, and radiology written examinations conducted by certifying boards test on verbal and quantitative knowledge. When academic programs are motivated to "teach to the test" emphasis will be on that type of knowledge. Within some of the certifying organizations there is an interest and effort to produce examinations that test on the ability to perform specific "real world" professional functions; for example: analyze an image with respect to its quality characteristics. This cannot be done with just verbal and mathematical knowledge. Oral examinations conducted in person by an examiner provide this opportunity and require knowledge extending beyond verbal and mathematical to include *sensory based concepts*. This is the type of knowledge required for many medical physics activities that we will now consider.

VIII.SENSORY BASED PHYSICS KNOWLEDGE

Learning physics and development of knowledge structures is an ongoing *natural human process* beginning at birth and continuing throughout life. It does not require formal educational programs with classrooms, teachers, and textbooks. Knowledge of physics, that is a mental representation of the physical universe, develops as we sense and interact with specific physical components around us. In Figure 3 we will use water as an illustration.,

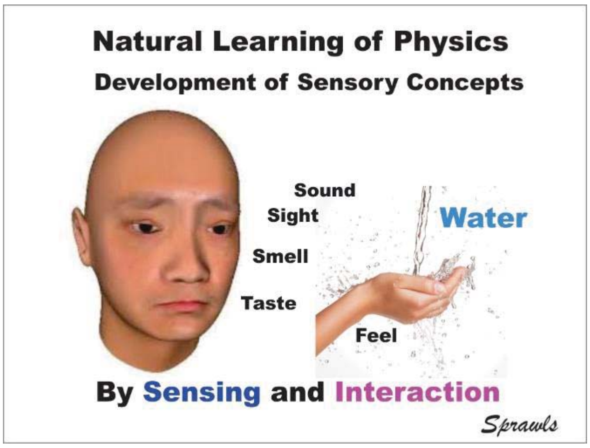

Figure 3. Learning the physics of water through sensory observations and interactions.

Water is a major component of the physical universe and is the object of much of our physics knowledge. This learning begins early in life as we experience the specific physical characteristics of water and also develop concepts of factors such as fluids and temperature. This is the knowledge that prepares us to live with and use water throughout our lives.

In academic physics courses the emphasis is on quantitative and mathematical symbolic relationships generally within the topic of hydrodynamics.

This guides us to a very significant observation. Symbolic quantitative physics, as taught in physics courses, is important and valuable for several reasons. One is to perform well on written examinations. It contributes to a comprehensive understanding in all areas of physics by showing the relationships among the many physics quantities. It is critical knowledge for performing many analytical and design functions. Determining radiation dose to specific patients, treatment planning, and shielding design are some examples.

However, for many activities, ranging from interacting with water in our daily lives to performing a variety of medical physics functions, a physics knowledge structure consisting of sensory based concepts is required.

IX. CONCEPTS

Concepts are the fundamental elements that make up our knowledge structures. They form the major part of our knowledge and play a role in all aspects of learning. Conceptual learning is what results from the natural human learning experience. It is different from symbolic verbal and quantitative learning but does provide a foundation and contribute to the significance and meaning of symbols (definitions and equations), especially in the field of physics.

The significance of conceptual knowledge is two-fold. It is for the most part developed by observation and interactions with specific areas of the physical universe. It is the type of knowledge that contributes to higher level mental functions including analysis, problem solving, innovations, etc. as illustrated in Figure 4.

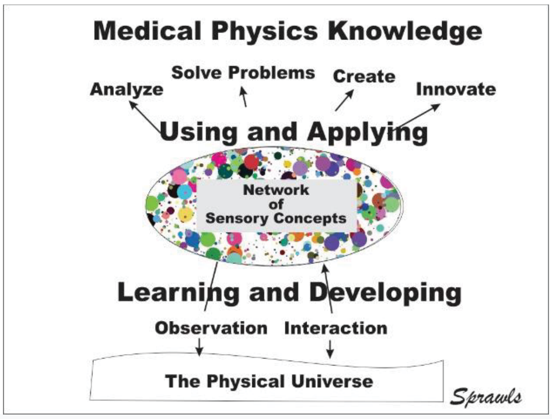

Figure 4. The significance of conceptual knowledge in medical physics education, the link between learning and applying.

Let us now enhance *our concept* of developing *physics concepts* using the illustration in Figure 5
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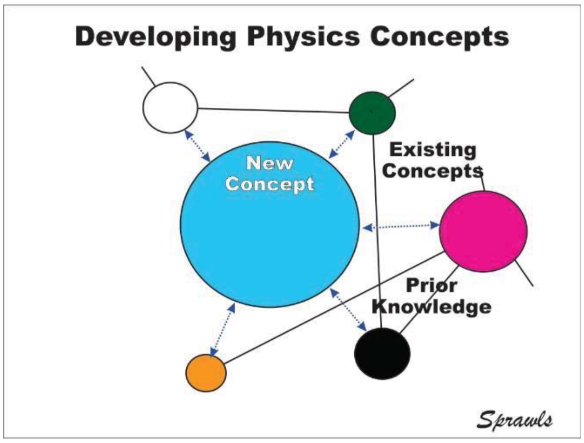

Figure 5. Illustrating the concept of how we develop concepts as part of our knowledge structure.

While developing concepts in our mind is a natural learning process as we observe and experience what we come into contact with, it is also a complex process as illustrated. This is a major factor we must consider as we develop educational programs and activities to promote conceptual learning. A person does not typically develop a new concept in complete isolation from other concepts and experiences. A concept is an element that is connected within our total knowledge structure.

Because knowledge is a network of concepts, development of effective knowledge structures is enhanced by the use of mind maps. An example is shown in Figure 6.

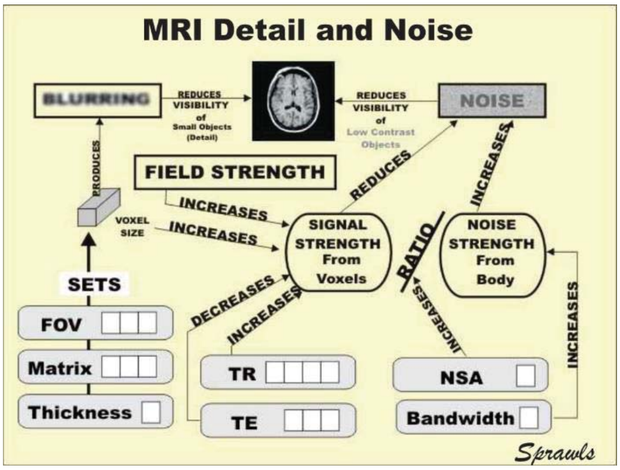

Figure 6. A mind map supporting the development of concepts related to MR image detail and noise. This and other mind maps are available in resources referenced later.

X. DEVELOPMENT OF EFFECTIVE EDUCATIONAL PROGRAMS AND ACTIVITIES

One of the major challenges for medical physics educational programs is that of developing learning activities that provide the appropriate *mixture* or *balance* among the different knowledge types, especially symbolic and conceptual. This requires establishing specific learning outcomes and objectives relating to what the learner/student is being educated to do. This distinction is illustrated in Figure 6.

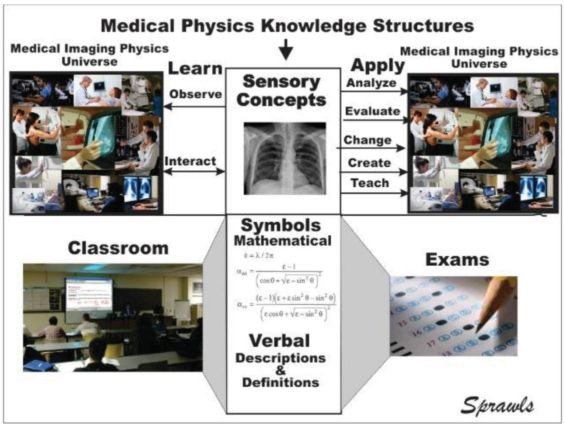

Figure 6. The development and application of the different knowledge structures.

There is a significant difference between preparing for examinations and preparing to perform many medical physics functions as illustrated. Classroom activities heavily based on verbal and mathematical symbolic representations. along with self-study, provide appropriate preparation for most written examinations.

Classroom based educational activities are relatively *efficient*, especially compared to one-on-one guided instruction in an actual physics environment, such as imaging patients with MRI and focusing on analysis and optimization of image quality. The type of education that can be provided in a classroom is extremely valuable but has significant limitations with respect to developing knowledge to support many medical physics activities. The following is a quote from the author.

"A classroom is like a box in which we enclose students separating them from the physical world about which they should be learning".

This is a major challenge in medical physics education. How to combine the *efficiency* of classroom (direct or online) learning with the *effectiveness* of learning by observation and interaction with actual physics functions such as clinical imaging.

Now with advances in technology including digital imaging, graphics, and ability to connect and communicate over the internet, there is the opportunity to provide highly effective medical physics learning activities in institutions anywhere in the world. When high-quality graphics and images are available in the classroom they provide a "window" to the external world of medical physics activities.

The objective is to build on the general efficiency of classroom instruction and make it much more effective in producing higher levels of learning to prepare for many medical physics activities.

XI. COLLABORATIVE TEACHING

The technical infrastructure supported by the internet and World Wide Web makes possible the process of *collaborative teaching* illustrated in Figure 7.

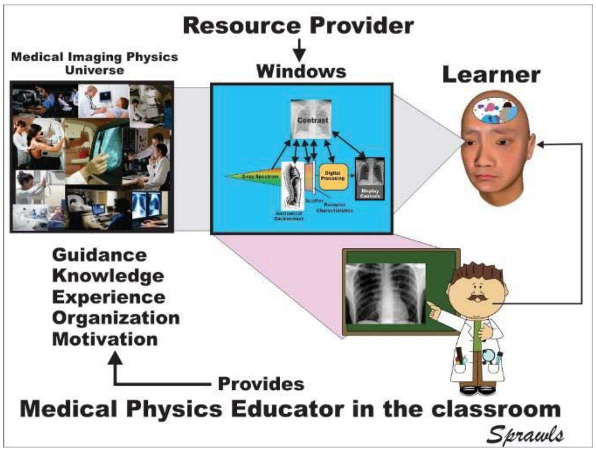

Figure 7. Collaborative teaching combines the knowledge and experience of classroom teachers with that of resource developers and providers to connect and provide windows in the classroom.

The great value and power of collaborative teaching is it makes use of the different knowledge and experience of two different medical physicists, the *classroom teacher* and the *resource provider*. The resources enhance and contribute to the effectiveness of the classroom teacher. The efforts of both are required to provide highly effective education and in a reasonable efficient process.

The resource provider is generally an experienced clinical medical physicist and educator with the capability of developing graphical and visual representations of medical physics phenomena associated with clinical procedures that contribute to the formation of sensory concepts. To contribute to enhanced medical physics education on a global basis the resources should be available at no cost to all educators. For the field of medical imaging physics an example is the *Sprawls Resources* on the web at: www.sprawls.org/resources .

Visuals developed specifically for use in classrooms (PowerPoint) are available at: http://www.sprawls.org/PhysicsWindows/ .

With these resources, especially high-quality visuals and images, classroom teachers can provide highly-effective learning experiences by adding their knowledge and experience and guiding the mental interactions and learning process.

Additional publications relating to collaborative teaching are references [1, 2, 3]

XII. SUMMARY AND CONCLUSIONS

Learning physics is a natural human process as we observe and interact with the physical environment around us. This interaction and experience is through the senses, especially visual, and contributes to the formation of a knowledge structure consisting of a network of concepts. It is this type of mental representation of the physical universe that then enables a person to interact through a variety of high-level mental functions including analysis, problem resolution, and creative activities. This applies both to everyday living and to the practice of medical physics. Symbolic verbal (words) and quantitative (mathematical) knowledge is critical for many human functions but does not support some of the high-level functions that require conceptual knowledge. Classroom activities can be limited in producing adequate conceptual knowledge because of the separation from the actual medical physics clinical activities. Classroom teaching is generally more effective in producing verbal and quantitative knowledge and preparing students for written examinations, but less effective in preparing for many applied medical physics activities.

Collaborative teaching is addressing this challenge by combining the knowledge, experiences, and efforts of different medical physicists to provide highly-effective classroom learning activities.

XIII. REFERENCES

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About the Author --- Perry Sprawls, Ph.D., is a clinical medical physicist and educator with extensive experience in medical imaging science, technology, and clinical applications. At Emory University, where he is now a Distinguished Emeritus Professor, much of his effort is devoted to introduction and optimization of new imaging methods, especially mammography, CT, MRI, and digital imaging in general. Throughout his career he has used his clinical medical experience to develop educational resources to help others. His belief is that clinically effective medical imaging requires both high-quality imaging technology and optimized procedures supported by medical physicists as members of the imaging staff, consultants, and as educators. This continuing effort is now supported by the Sprawls Educational Foundation, www.sprawls.org