EDUCATIONAL RESOURCES

WINDOWS TO THE WORLD OF MEDICAL IMAGING PHYSICS VISUALS FOR EFFECTIVE AND EFFICIENT LEARNING AND TEACHING

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Abstract— **Modern medical imaging using highly-developed methods and modalities is a complex process with many adjustable factors that determines the characteristics and quality of images. The goal of each clinical procedure should be images that are optimized to provide visibility of the significant anatomical and pathological features to contribute to effective diagnoses and therapeutic procedures. That requires a team of medical imaging professionals, including radiologists, technologists, and physicists, with the knowledge of physics that can be applied to evaluate images and control the complex imaging process. A challenge in medical physics education is that of providing learning activities that contribute to the development of a foundation knowledge rich in sensory/visual concepts that are needed for clinical physics applications in the field of medical imaging. Through the process of *collaborative teaching* medical physics educational programs anywhere in the world are now providing highly-effective learning activities by combining the knowledge, experience, and leadership of local physicists with *Windows to the World* developed and provided by an experienced clinical physicist and educator connected with the internet through the website: www.sprawls.org/PhysicsWindows .**

Keywords – ***Concepts, visuals, image quality, optimization, teaching***

I. INTRODUCTION

Radiology, roentgenology, and the expanding field of medical imaging ~~provides~~ methods for detecting and diagnosing diseases and effects of trauma in addition to providing visualization for the planning and guiding of therapeutic procedures. With the expanding capabilities and complexities of modalities, including MRI, CT, digital radiography and mammography, and radionuclide imaging, the "human factor" is a critical element in the overall imaging system and process. These are the medical imaging professionals including radiologists, radiologists in training, radiographers, technologists, and medical physicists both in their roles as members of the clinical team and as educators for all medical imaging professionals.

An appropriate goal for every imaging procedure is that it be *optimized* to provide visibility of both normal anatomy and pathological conditions and to balance image quality with any potential risks or other competing factors. This is often a complex process because of the many imaging protocol factors that must be considered together to produce an optimized procedure. To achieve this, the medical imaging professionals with responsibility for the clinical procedures must have an appropriate knowledge of the physics of the imaging process and its application within the clinical setting. This includes a comprehensive knowledge of image characteristics, the methods for producing images and the many factors that affect image quality. A major requirement is the ability to analyze and evaluate images in the clinic, determine if they are optimized for specific clinical objectives, and make adjustments of procedure protocols as necessary. This requires a mental knowledge structure consisting primarily of *sensory (visual) concepts* rather than just symbolic elements including words, abbreviations, and mathematical symbols.

A continuing challenge in medical physics education is providing learning experiences that bring medical imaging professionals into the clinical imaging process, with the knowledge to obtain images with the optimized quality characteristics for more effective diagnosis and treatment of diseases along with managing risk and other competing factors.

Windows to the World of Medical Imaging Physics is a web-based resource for medical physics educators and teachers, to use in their classes and other activities to help learners develop more effective knowledge for applying physics to clinical medical imaging.

II. KNOWLEDGE STRUCTURES OF THE PHYSICAL UNIVERSE

Our knowledge of physics is actually a mental representation of the various segments of the physical universe, with medical physics being the segment of our interest at this time. Knowledge is a complex network of various elements . For a specific field, such as medical physics, there can be very different knowledge structures depending on the learning experiences and *how it was taught*. Two major types and very different knowledge elements are *sensory concepts* and *symbolic representations*. Symbolic representations include *words* used to provide definitions and descriptions and *mathematical symbols* to describe the quantitative characteristics and relationships.

Effective Knowledge Structures: The effectiveness of someone's knowledge is determined by the functions or tasks that they need to perform. An example is the distinction between applying physics to improve medical imaging procedures and that of performing well on academic tests and examinations. That is a major issue facing medical physics education today.

The application of physical principles to control and improve medical imaging procedures and related clinical activities requires a knowledge rich in *visual concepts*. On the other hand, within our academic programs today there is often emphasis on preparing learners for examinations both in the courses being taken and for various professional certifications.

For a specific educational program it is not a question of good or bad, or right or wrong, but that the program must be designed and conducted with learning objectives that relate to the functions the learner/students are expected to perform The success of learners in applying what they have learned to perform specific functions does not depend only on the scope and depth of knowledge, but very much on the types of knowledge structures. This concept is illustrated in Figure 1.

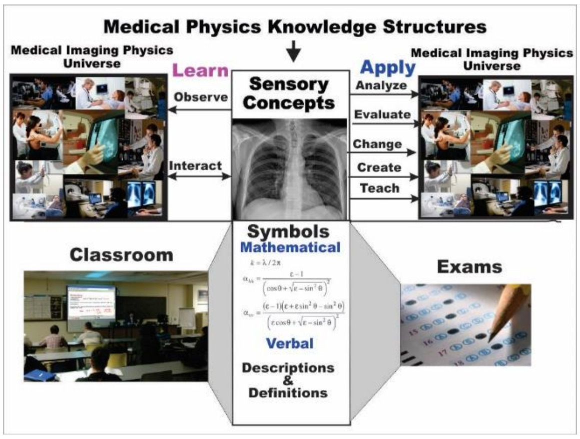

Figure 1. The overall concept relating knowledge structures to both learning and applying.

Knowledge structures for a specific subject, such as medical physics, can be predominantly conceptual, predominantly symbolic, or a combination of both.

For physics knowledge that is to be applied in clinical medical imaging the most effective structure is one that is predominantly conceptual serving as a foundation, with symbolic elements, mathematical and verbal, added to it.

As medical physics educators our greatest challenges and opportunities for the future are developing and conducting learning activities (classroom, small-group, laboratory, clinical, etc.) that will produce the most appropriate knowledge structures.

Every learning activity, especially those in the classroom, has two conflicting characteristics, *effectiveness* and *efficiency*.

Effective Learning Activities: The effectiveness of a learning activity determines the ability of a learner to perform specific functions or tasks. Here we consider two examples. One example is optimizing a CT procedure with respect to quality and dose. Another example is getting a high score on a written examination. An effective learning activity for the first is one that develops knowledge consisting predominantly of visual concepts. For the second, preparing for written examinations, effective learning activities and teaching typically need to emphasize symbolic knowledge, including verbal definitions or descriptions and mathematical symbols and relationships.

A major factor in developing and providing medical physics educational programs and activities is that all medical imaging professionals, including medical physicists, do not need the same type of knowledge structures because they will be performing very different functions and tasks. For example, a radiologist who will be visually evaluating CT image quality and optimizing procedures needs a knowledge rich in visual concepts while a medical physicist calculating the dose for a CT procedure needs a strong symbolic knowledge of the mathematics.

Efficient Learning Activities: The efficiency of providing a learning activity is determined by the cost and effort required. This includes faculty time and effort, availability and cost of resources and materials, availability and access to institutional facilities (especially clinical imaging facilities).

The different types of knowledge structures with respect to their effectiveness and efficiency will now be considered.

III. SYMBOLIC KNOWLEDGE STRUCTURES

Let's continue with the idea that knowledge of physics is a representation, or model, of segments of the physical universe within the human mind. These structures consist of complex networks of concepts and symbols.

Verbal Symbols: Verbal symbols, or words, are the foundation of human communications, both spoken and written. They are essential parts of physics knowledge and teaching when used appropriately.

For some academic fields of study, knowledge consisting primarily of words might be sufficient for the established learning objectives of a course, especially when the learning focuses on memorizing facts and definitions. However, for clinical medical physics, knowledge consisting of words is not sufficient… unless the only objective is to pass a written examination.

There are two major reasons why medical physics education is often "over weighted" with verbal symbolic knowledge. It is *easy to teach* and *easy to test*. It is efficient but the problem is that it is not effective for clinical applications.

It is much easier and efficient to prepare a test or examination based on verbal knowledge such as definitions, descriptions, and facts than testing on conceptual knowledge or ability to apply. This ranges from short tests within courses to major certificating examinations. However, there is an effort with some examinations to move to more of a conceptual and image based approach.

One of our great challenges as medical physics educators is to "teach beyond the test." While preparing our learners to perform well on examinations is necessary the learning objectives and activities should also prepare for the application of physics in the real world of clinical medical imaging.

Teaching physics with words is highly *efficient*. It can be done by lecturing, writing on the board, and showing PowerPoint text. This can occur in a classroom completely separate and isolated from the clinical environment or through web-based activities. It is efficient because it does not require effort or resources to connect the learners to the clinical environment that would be required for higher levels of learning.

Mathematical Symbols and Equations: Physics, including medical physics, is a highly quantitative science. In almost all applications it is necessary to know the values of physical quantities and the relationship to other quantities and factors. These relationships are described with equations or graphs. In virtually all realms of the physical universe, the science of physics can be represented as a quantitative model using mathematical symbols. This is essential knowledge for many applications not only to understand the physical quantities but to use the relationships to determine the values of other quantities by calculations or graphical methods. Here we will use an example. In CT the tissue voxel size is a major factor in image quality and acquisition time. It is determined by a combination of three (3) adjustable protocol factors and the relationship is expressed by Equation 1.

$$V_{mm3} = (FOV_{mm}/M_{voxels})^2 \text{ x } t_{mm} \tag{1}$$

This is necessary knowledge for optimizing image quality when specific values are required. It is easy to teach. Like verbal descriptions discussed previously, learners can memorize the equation, plug in values, perform the calculations, practice by working problems, and perform well on examinations. However, if knowledge is limited just to the mathematical model, what will be missing is a complete and comprehensive understanding of the actual physical reality. What are those various quantities and how do they fit into the overall imaging process? Can the learner visualize the physical items, such as matrix size, or just know it as a mathematical symbol.

As physicists the mathematical model is often our usual representation of the physical universe. It is how we were taught because we were being prepared to become physicists. Mathematics is the tool we use for many functions including analysis, design, modeling, and much more. We could not practice physics without it.

For all who apply knowledge of physics to clinical activities, understanding of the quantitative is important, *but not sufficient*. For example, optimizing a CT imaging protocol in the real world is not done by solving equations. It is done by visualizing the different characteristics of image quality and their relationships.

The most effective knowledge for applied clinical physics is a strong foundation of visual (sensory) concepts onto which the verbal and mathematical knowledge is added. We will now consider how these highly effective knowledge structures can be developed.

IV. SENSORY CONCEPTS

Our fundamental and most significant knowledge of the physical universe (physics) is in the form of *sensory concepts*.

Natural Learning: The learning or development of sensory concepts *occurs naturally* as one experiences the physical universe through the senses, vision, hearing, taste, smell, and feel. This begins early in life well before language capabilities are developed. Our greatest knowledge of the physical universe is in the form of sensory concepts developed throughout life, and most outside of school and formal education.

Application of Knowledge: It is knowledge in the form of *sensory concepts* that is required to effectively interact with our immediate surroundings for functions ranging from selecting the appropriate food items at the market to analyzing and optimizing medical imaging quality. The development of one (selecting food) has occurred naturally as we experienced the market place, especially through the senses of vision, smell, and anticipated taste.

The challenge and opportunity for medical physics educators is to provide learning opportunities for all medical imaging professionals to develop a strong sensory concept knowledge that will support clinical applications.

The Concept of Sensory Concepts: Water is one of the most common components of the physical universe that we interact with constantly. Our fundamental knowledge of water is in the form of a rather comprehensive set of sensory concepts developed through experiences and interactions with water illustrated in Figure 2.

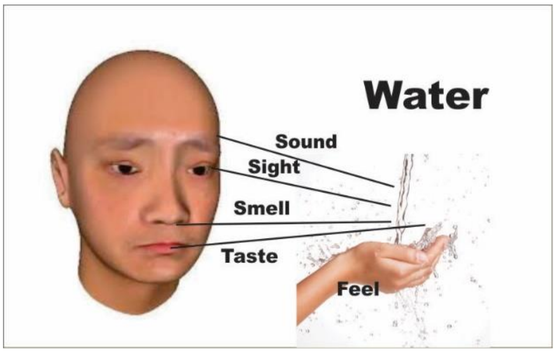

Figure 2. Developing concepts of water by experience through the senses.

A great value of a sensory concept is that it includes many of the characteristics of the physical object. Not only do we have a general concept of water, we have concepts of the individual characteristics, their significance and effects along with sources and perhaps how to make changes. The significance of sensory conceptual knowledge is that it provides for interacting with and controlling the physical objects. For example, if we are washing hands and the water feels too cold we know to adjust the temperature.

Let's now move from water to a medical image characteristic as shown in Figure 3.

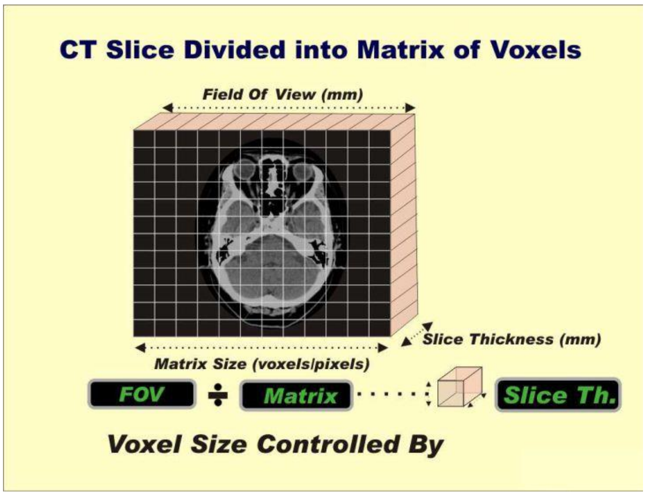

Figure 3. A visual representation of a CT image slice of tissue and the adjustable protocol factors that determine voxel size.

In the various tomographic imaging methods, including CT illustrated here, the size of the tissue voxels is a major contributing factor to several image quality characteristics, especially noise and detail, and must be considered in optimizing protocols.

Here we have the opportunity for comparing two methods of teaching this specific topic to medical imaging professionals. One is the mathematical approach by presenting Equation 1 and working through example calculations. The other is presenting the visual in Figure 3. and guiding the learner in exploring the factors and relationships. Let's continue the comparison in terms of *effectiveness* and *efficiency*. There is no doubt that the visual approach is highly *effective* for developing concepts that support clinical applications. However, it is much less *efficient* for the teacher than just presenting the mathematics because it requires the production or availability of the visual representations.

The significance of knowledge consisting of sensory (especially visual) concepts in fields of study including clinical medical physics is summarized and illustrated in Figure 4.

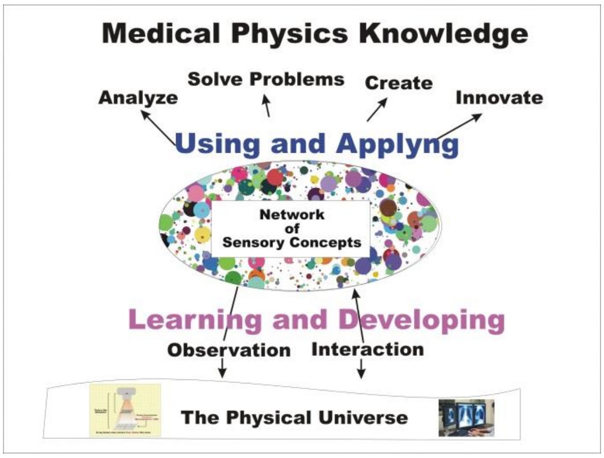

Figure 4 The Development and Application of Knowledge Consisting of Sensory Concept Networks.

Sensory concepts are essential knowledge elements for many physics applications. While learning and developing sensory concepts is a natural human process that occurs as we observe and interact with the physical universe around us, formal educational activities are required to develop the necessary knowledge in fields of study such as medical physics.

V. HIGHLY EFFECTIVE AND EFFICIENT LEARNING ACTIVITIES

A highly-effective learning activity in medical imaging physics is one that develops a comprehensive network of visual concepts. This can be achieved by connecting the learner to the medical imaging procedures and providing guidance by an experienced medical physics educator. While there is value to having these in the clinic with direct access to the equipment, clinical procedures, and resulting images, it has limitations. It can interfere with clinical activities and cannot accommodate many learners at any one time. While being effective it is generally not very efficient because of many factors including the limited availability and expense of clinical facilities for teaching and it is not practical for large class sizes.

Visualizing the Invisible: Much of the physics universe associated with medical imaging is invisible. This not only includes the radiation that is used to form images but much of the imaging process that occurs at the atomic and microscopic level. There is much more than just seeing the equipment, the patient, and the resulting images. Another challenge in understanding the imaging process is the ability to visualize the sometimes complex relationship among the various factors and their effects on image characteristics and quality. This requires providing learners with resources that can be used to visualize and develop concepts of the invisible.

VI. WINDOWS TO THE WORLD

Let us think about the typical classroom used for medical physics courses. It is in reality like a large box in which we enclose our learners separating them from the real world of clinical medicine and medical physics about which they should be learning.

What is needed are "windows" in the classroom through which selected segments of the physical universe can be viewed.

Now with the availability of digital imaging and graphics technology, the internet and World Wide Web, and the concept of collaborative teaching and shared resources that is now possible as illustrated in Figure 5. The *Windows* project and resources consists of an extensive collection of visual illustrations, for the most part focusing on the elements of the medical imaging process that are not generally visible.

Creation and Development: The visuals or "windows" provided in this project are created by a medical physicist (the author) with extensive experience in both applied clinical physics and education. They are designed to provide visual access--"windows"-- to all aspects of the medical imaging process from the classroom, in textbooks, and online modules. The goal is to contribute to the development of knowledge structures within the learner's mind that will support the application of physics to clinical medical imaging.

Collaborative Teaching: Consider teaching as the process of *helping someone*, the learner, develop appropriate knowledge structures. In some classes this might be in the form of a lecture attempting to transfer knowledge from the brain of the teacher to the brain of the learner. As discussed previously, this is highly efficient but not at all effective, especially for medical physics. Effective teaching requires the opportunity to develop visual representations of the physical process and a network of sensory, usually visual, concepts.

The production of appropriate visuals by individual teachers is not realistic or efficient. It requires great time and effort in addition to extensive experience and insight into the application of physics to the medical imaging procedures.

The process of *collaborative teaching* is increasing both the effectiveness and efficiency of medical imaging physics in virtually all countries of the world. For each class or learning activity the team of collaborating teachers consists of the local teacher working directly with learners and the remote teacher, somewhere in the world, who is creating and providing the visuals. The local teacher meeting with the class is a major contributor to the learning process by organizing and guiding the observation and interaction with the physical universe but also sharing personal experience and knowledge. It can also be an opportunity for the teacher to be a role model demonstrating the valuable contributions of medical physics to clinical medical imaging.

The concept of collaborative teaching using the visuals provided by the *Windows* project is illustrated in Figure 6

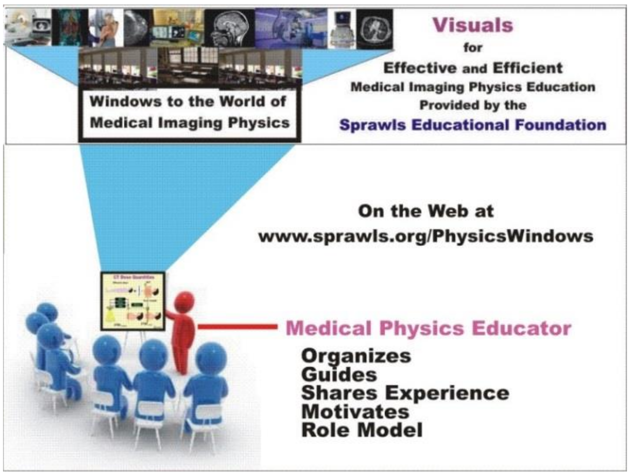

Figure 5. The Windows project brings the world of Medical Physics into the classroom.

Medical physics educators and teachers can now access and use the visuals in their classes and other learning activities by going to:

www.sprawls.org/PhysicsWindows .

VII. CONCLUSION

Medical physics education, specifically in the field of medical imaging, is becoming both more effective and efficient in virtually all countries of the world through the process of collaborative teaching. The local medical physics educators or teachers devote their efforts to organizing and guiding the learning process along with sharing their knowledge and experience. The visuals provided by the collaborating teacher, connected through the internet, contribute to the development of highly effective visual concepts that are required for clinical applications and as a foundation for additional symbolic knowledge.

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