EFFECTIVE PHYSICS KNOWLEDGE FOR DIAGNOSTIC RADIOLOGISTS

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Abstract— — **Physics is one of the fundamental sciences of radiology along with the biological sciences anatomy, physiology, and pathology. Physicians, especially radiologists, require a comprehensive knowledge of physics, along with the other sciences, for the purpose of performing diagnostically effective and optimized medical imaging procedures. This requires learning objectives that are generally different from learning physics in preparation for certifying examinations. Physics educational activities for residents beginning with and structured around images as the principle physical object provide many values. It is of more interest to residents and provides a strong connection between physics and clinical radiology. The most significant factor is that learning physics from images develops higher levels of mental knowledge structures and conceptual networks that are required in clinical radiology. The innovative contributions of three pioneers in the field of education, Blume, Dale, and Gagné, provide guidance in developing and conducting physics education for residents that is of value in the practice of clinical radiology. Most of the activities described are based on radiology education programs in North America but have applications in other regions of the world.**

Keywords— **Images, Concepts, Clinical, Examinations, Educator.**

I. INTRODUCTION, OVERVIEW, AND OBJECTIVES

Images are the most significant physical objects used for the detection, diagnosis, and management of therapeutic procedures within the practice of clinical medicine. The appropriate and effective use of medical images for specific clinical conditions depends on the knowledge and experience of physicians, especially radiologists, who perform the procedures. This includes knowledge of both the biological conditions within the human body and the physical characteristics of the images and the imaging procedures. It is the physical characteristics of the images that determine the visibility of specific anatomical structures, biological functions, and signs of pathology. In principle there are images with optimum characteristics for each specific clinical procedure and imaging objective. The responsibility of the radiologist is to assure that the selected image characteristics are appropriate for the specific clinical objective. Especially with the more complex imaging methods, CT, MRI, etc. the radiologist is a significant factor in image quality control and assurance.

This requires a comprehensive *conceptual knowledge* of physics organized around *images* as the major mental element. This is somewhat different from knowledge learned, applied, and often taught by physicists that is more *symbolic and quantitative* in nature. Effective physics education for radiology residents and practicing radiologists must be different from traditional medical physics courses in both content and organization.

Images are physical objects with a combination of physical characteristics, and physics is a basic science of radiology. This is as significant as anatomy, biochemistry, physiology, and pathology as the basic biological sciences of the human body. All of these are the fundamental sciences of diagnostic radiology. Knowledge of each is essential to the practice of radiology as illustrated in Fig. 1.

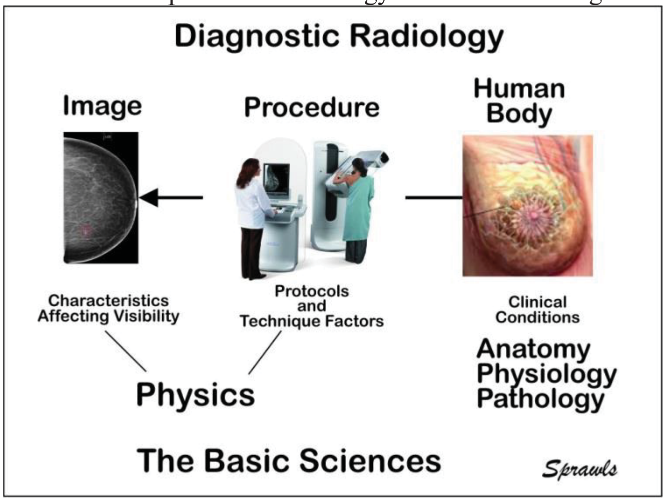

Fig.1. The basic and foundation sciences of diagnostic radiology.

There is a major factor distinguishing physics from the other basic sciences. The sciences related to the human body are included in medical school curricula and applied and enhanced throughout clinical activities. Physicians entering radiology residencies have extensive knowledge of these sciences, but not of physics, specifically the physics of images and the imaging process.

The significance of physics knowledge is officially recognized by the radiology profession through several requirements. Physics is a required subject to be provided in accredited radiology residency programs. It is also a specific topic within radiology board certifying examinations. The assumption is knowledge of physics is a significant requirement for the practice of clinical radiology and the role of certifying examinations is to verify that residents have acquired that knowledge. However, the reality is that effective clinical practice versus passing examinations requires different types of physics knowledge.

This is not intentional but results from the format of written physics examinations and the passing of the examinations as a major priority for residents.

Within radiology residency programs physics learning activities (classes, modules, board reviews and practice examinations, etc.) generally fulfill the requirements to pass examinations. However, they do not provide adequate knowledge of physics relating to images and the imaging process. This is especially significant for the complex decisions that need to be made by radiologists in the optimization of procedures with the highly- advanced contemporary imaging methods.

The objectives of this article are not to provide a detailed step-by-step "cookbook" instruction on how to teach physics to radiology residents. Around the world and in our individual institutions there are many different conditions, requirements, needs, and challenges relating to teaching physics in radiology programs. There is no one approach that is appropriate for all. The objective is to provide a review of some major developments and innovations in the educational process along with resources so that those of us who are medical physics educators/teachers can continue to optimize our programs to help radiologists develop mental knowledge structures that support their practice of clinical radiology.

II THE ELEMENTS OF AN EFFECTIVE PHYSICS PROGRAM FOR RADIOLOGISTS

To be effective and provide radiologists with physics knowledge that can be applied to enhance clinical performance throughout a career the program must be designed and conducted based on established principles of both the learning and teaching process. A major factor is the recognition of the types of mental knowledge structures required to support specific functions, especially in the clinic, and then the design of learning activities to develop the required knowledge. There is a longstanding and continuing challenge that results from a combination of factors relating to the balance of *effectiveness* and *efficiency* of physics learning activities within residency programs. It is also heavily driven by the goals and objectives for the physics classes and study activities, either teaching for the *test* or teaching for the *task* of being a highly effective clinical radiologist. There is a relationship between characteristics of *learning activities* and *levels of learning* that determine how knowledge can be used. A critical factor is connecting physics knowledge to clinical activities, both for learning and applying in the practice of diagnostic imaging. Our opportunity as medical physics educators is to use the extensive research, developments, and innovations in the broader field of education to provide highly effective physics learning activities for radiologists, now and into the future.

III. LEARNING FROM THE PIONEERS

Our profession of medical physics and clinical applications is built on the work and innovations of many pioneers in the field, especially beginning with Roentgen and many to follow. There are also pioneers in the field of education that provide us with an understanding of the process of learning and the development of knowledge structures in the brain and the characteristics of learning activities for developing the different types of knowledge. Here we will learn from three.

Blooms Taxonomy

Benjamin Bloom, an educational psychologist, developed a model of the learning process, *Blooms Taxonomy* that consists of six levels of knowledge ranging from simple memory to the higher cognitive levels supporting functions including analysis, problem solving, and creativity. This has provided educators with guidance in developing learning activities that provide effective knowledge for "high level" professional activities and goes beyond teaching to the test. For additional information and references search on "Blooms Taxonomy" in Wikipedia at: https://en.wikipedia.org/

Dale's Cone of Experience

Edgar Dale developed a model, *Dale's Cone of Experience* that organizes the different types of learning activities in relationship to their *effectiveness* and their *efficiency*. Effectiveness ranks learning activities in their ability to develop knowledge for specific mental functions--generally those as described by Bloom. Efficiency ranks the "cost" of the learning activities for a combination of factors including time and effort for both teachers and students, availability of resources for learning, and conflicts with other activities and scheduled events. For additional information and references search on "Edgar Dale" in Wikipedia at: https://en.wikipedia.org/

These two models as they apply to the physics of diagnostic radiology are illustrated in figure 2.

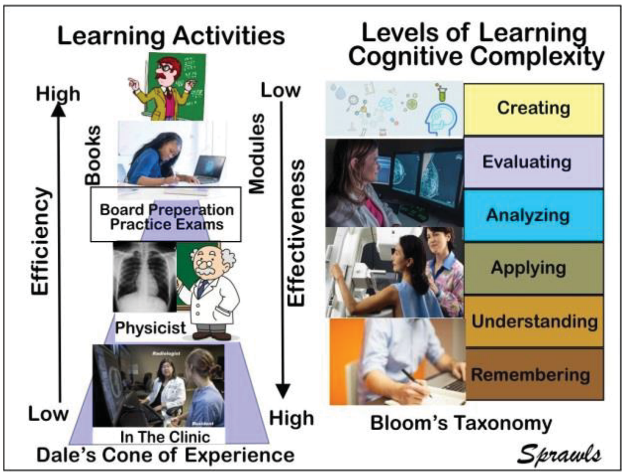

Fig.2. Two models of the learning process as they apply to the physics of diagnostic radiology.

A major factor as illustrated by Bloom's Taxonomy is that there are different levels of learning, or cognitive/mental complexity, associated with or required for the range of mental activities. Here we will emphasize a major difference between two, taking examinations and conducting appropriate medical procedures including the analysis of images or effective diagnosis and guidance of treatment.

Gagné's Conditions of Learning Events of Instruction
Robert Mills Gagné was an American educational psychologist best known for his *conditions of learning*. His pioneering work was in adult education developing educational methods to train aircraft pilots. A result was his model of the educational process as a series of nine specific events, each requiring actions by the educator. For additional information and references search on "Robert M. Gagné " in Wikipedia at: https://en.wikipedia.org/.

The application of his model to learning physics by radiology residents is illustrated in Figure 3.

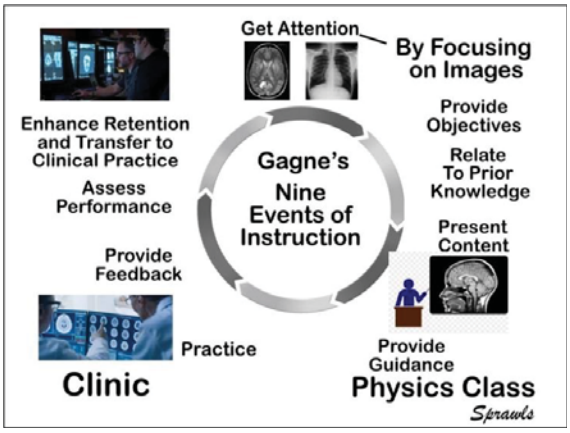

Fig.3. The series of nine events applied to the development of physics knowledge for clinical radiology.

The value of this is not to provide a detailed step-by-step guide to teaching but for those of us who are the physics educators to provide some perspectives on the adult learning process and find appropriate applications. Both the physics class/conference room and the clinic are necessary learning environments for physics that can be applied in clinical radiology. A major value of the physics class/conference is the medical physicists who use their knowledge and experience to connect residents to images as physical objects with specific characteristics that determine their clinical applications. The first of the nine events is to get the resident's attention. This is achieved by beginning with images, not physics equations. This provides the opportunity for explaining the objectives, which is the capability to understand image characteristics for all of the modalities and apply to both producing and interpreting clinical images. Along with this residents can recall from their prior clinical knowledge and experience clinical procedures in which a better knowledge of the image characteristic would have been helpful. This now provides a receptive opportunity for the presentation of the physics of imaging and guiding the learning process.

The image-based physics learning process then continues in the clinic and will benefit from guidance provided by radiologists. The significance is that many subjects, and especially physics, are most effectively learned under conditions where the knowledge is to be applied. The opportunities are to observe and interact with actual clinical imaging procedures, be evaluated and mentored, and use this learning experience in continuing clinical practice.

IV. DIVERGING OBJECTIVES OF PHYSICS EDUCATION FOR RESIDENTS

Traditional written examinations, including computer based, are designed to test the recall and perhaps some degree of understanding of factual knowledge generally in a symbolic form. This includes verbal definitions and quantitative mathematical relationships. This is driven by two factors. A word or mathematical based examination is relatively easy to develop and score and the content of examinations is determined by the curriculum of the educational programs that is the general preparation for the examinations.

It is this strong inter-dependence between radiology residency physics education and the certifying examination process that is a major factor in moving to more clinically valuable and effective physics knowledge.

With the first professional objective being to pass certifying examinations it is human nature to have educational activities with residency programs to prepare for this. A significant factor is physics classes within a residency program completely separated from clinical activities and restricted to times that will not interfere with a resident's clinical work. It is an issue of priority within a Radiology Department. The directives to the medical physicists, who provide the educational activities within a residency program, direct or implied, are to make sure the residents pass the certifying examinations.

A general result is that the physics education within residency programs is significantly isolated from clinical education in several ways. A major one is the limited "quality" time that is available with residents and not interfering with clinical work and clinical education. Physics education to prepare for certifying examinations and within limited time and available resources must be highly *efficient* as illustrated in Dale's model, Figure 4. This can be achieved with lectures by physicists, self-study of books and online modules, and especially board-preparation courses, mock examinations, etc. This is not being critical but is recognizing the requirements and limitations applied to physics education for radiology residents and *future radiologists!*

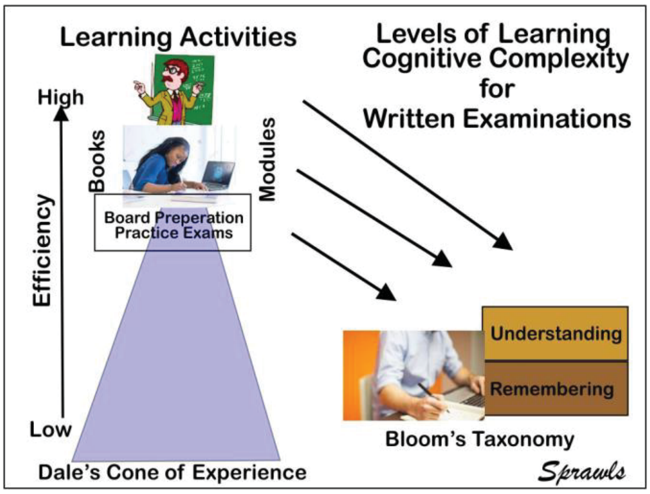

Fig.4. The learning activities that provide preparation for written examinations.

Compared to more clinically related physics learning activities to be described later the process of teaching and learning physics for written examinations is relatively *efficient*. It can be provided with lectures to groups and individual self-study. It does not require access to clinical facilities or one-to-one faculty involvement.

While the physics knowledge developed in these activities and tested for in written examinations is of significant value in the practice of radiology it is heavily symbolic, consisting of words and mathematical quantities and relationships. It does not provide the highly visual conceptual knowledge that contributes to the practice of clinical radiology.

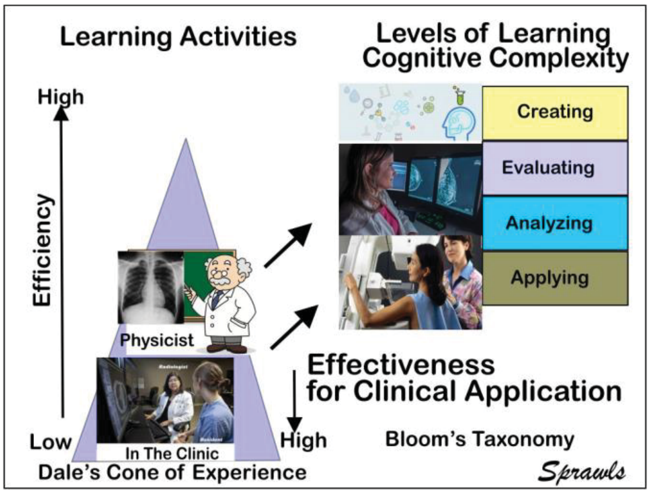

Fig.5. Physics teaching and learning activities that contributes to the effective practice of clinical radiology.

V. IT'S ALL ABOUT THE IMAGE

Radiology is the process of producing and evaluating conditions within the human body with *images.* An image is a physical object with specific physical characteristics with physics as its basic science. It is the interface between the field of physics and clinical medicine. It is the logical beginning and first activity for radiology residents learning physics with the guidance of medical physics educators.

A Transition from Tradition

The typical published curricula, textbooks, and physics courses for radiology residents begin with topics including the structure and characteristics of atoms and nuclei, forms of energy, electrical circuits and some associated technology. While this is essential knowledge it is not the optimum point to begin with for learning the physics of radiology.

Residents find it boring, a repetition of previous physics courses, and of little apparent significance to clinical radiology. This has contributed to the traditional physics course being perceived as something to be endured because attendance might be required and it will be on certifying examinations. Also, the physics classes might be scheduled at undesirable times so they do not interfere with clinical productivity and learning real radiology!

These are the conditions and perceptions that are being changed to provide more effective and clinically related physics education for radiology residents and future radiologists. The objective is not to eliminate the fundamental topics of atoms, radiation, etc. but to place them in more appropriate places within the curriculum.

Begin With the Image

Beginning a physics course for residents with an introduction to image characteristics as illustrated in Figure 6 provides several values.

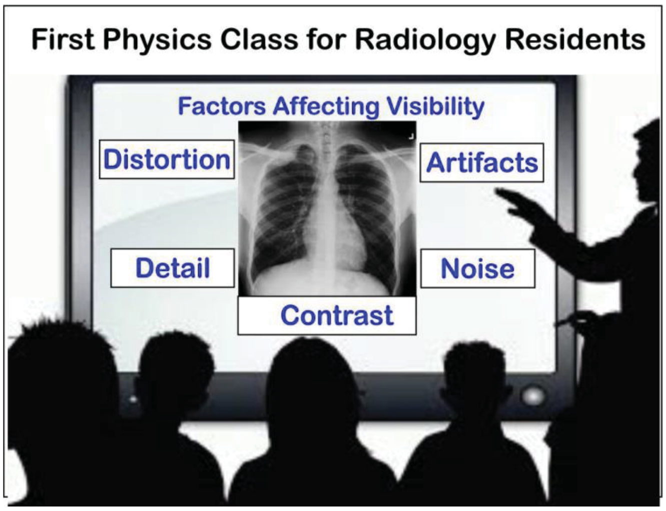

Fig.6. Beginning a Physics Course with Images as the Topic.

Beginning the learning of physics for radiology residents with a focus on images has many values. Images are physical objects with physical characteristics. The most significant factor is that images provide the most direct interface between physics, the science, and clinical radiology.

Residents come to the first physics class with extensive experience and interest in images. There is an inherent motivation to learn. This begins to provide an understanding of the complexity of medical images as produced with the various modalities and the combination of characteristics and factors that determine the visibility of specific anatomical structures and pathological conditions within the human body. Images establish an immediate interaction between physics classes and clinical activities, enhancing the role of physics as one of the clinical sciences.

The Universal Image Characteristics that Affect Visibility

A major and fundamental concept to be established, before studying the individual imaging modalities and methods, is that all medical images have a set of common characteristics that collectively determine clinical visibility. These image characteristics apply to all modalities. It is the physical characteristics, technology, and procedure protocols of each modality that determines the value of each of the image characteristics.

After developing knowledge of the common physical characteristics of images, contrast, detail (as determined by blurring), visual noise, artifacts, and spatial distortion, and their effects on visibility in relationship to the physical characteristics of objects within the human body, a next topic is the structure of digital images and the relationship of their structural and quantitative characteristics to image quality. This is fundamental and applies to all imaging methods.

The general characteristics of radiation, especially spectra, along with radiation quantities and units, are fundamental to most imaging methods and fit into the curriculum at this point. Details on production and controls will be of more interest when learning about specific modalities. Mammography is a good example.

The Imaging Modalities, Methods, and Procedure Protocols

The process of medical imaging consists of a hierarchy of three specific domains, *modality*, *method*, and *protocols*, with each based on physical principles. An example: MRI is a *modality*, spin echo is a *method* within that modality, and the *procedure protocol* consists of the selection and adjustment of factors within the method, including values for TR and TE. The characteristics and quality of images along with factors such as radiation exposure or image acquisition time are determined by the physics associated with each domain. Radiologists interact at each of these domain levels but in different ways.

The significance is physics learning activities for each domain have different requirements. The physics of the modalities and methods is most effectively and efficiently taught in classes or conferences by medical physicists. However, the procedure protocols and associated physics are learned in the clinic under the guidance of radiologists. This is most effective only if it is built on the physics knowledge of the modalities and methods provided by the medical physics educators. This is through a collaborative relationship between physics classes and clinic activities as illustrated in Figure 6.

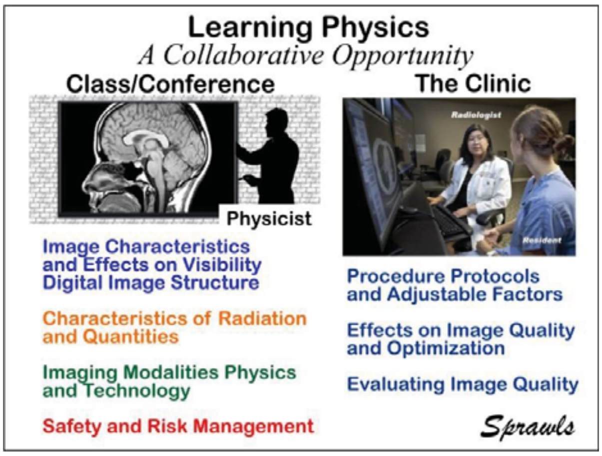

Fig.7. The comprehensive and collaborative process for developing clinically effective physics knowledge for radiologists.

VI. REMOVING THE BARRIER

One of the continuing challenges in physics education for radiologists is the real or perceived barrier between the physics classroom and clinical radiology, *and the recognition of physics as one of the fundamental clinical sciences.* Some of the factors contributing to this barrier have already been described. These have included the requirements to “teach to the test” with little vision for preparing radiologists for clinical careers. Perhaps an overlooked reality is that physics knowledge enhanced in the clinic is valuable preparation for certifying examinations. This is supported by the evolution of the physics sections on certifying examinations to be more image based and clinically relevant.

The more effective integration of physics knowledge into clinical radiology is being achieved by efforts on “both sides of the barrier”.

The Physics Class or Conference

The major values of physics classes within a residency program are the medical physicists who are interacting and leading the learning process. They provide an opportunity for residents to see medical physicists as collaborating professionals in the practice of radiology and medical imaging. It is where medical physicists can help establish *physics* as one of the significant *clinical sciences* specific to the field of radiology.

This value is especially realized when medical physicists use their knowledge of physics and continuing experience to help residents view and interact with images. This is a critical action in removing the barrier between physics classes and clinical radiology. It is in the physics classes, conducted by medical physicists, that residents learn the characteristics of images that affect and control visibility of conditions within the human body, the physics, technology, and capabilities of the many imaging modalities and methods. This is an essential foundation for using images in clinical applications.

The scheduling and location of physics classes can convey considerable factors contributing to the barrier. This is especially true when physics education is "something different" from clinical education and should not be allowed to interfere.

Physics Education in the Clinic

Physics is the foundation science of medical imaging in all clinical applications. Knowledge of physics is required to effectively utilize the many imaging methods in relationship to the clinical conditions within the human body. It is the extensive diagnostic capabilities and complexity of the modern imaging methods that enhance this requirement for a comprehensive and applied knowledge of physics for radiologists.

A major characteristic of learning a topic, including physics, which is to be used and applied in a clinical activity, is that the learning needs to occur along with actually performing the activity. Effective learning of the topic—physics--requires interaction with the activity, the physics environment, and a cycle of events as illustrated in Figure 8. This is a major factor between *learning to know* (for examinations) and *learning to apply* (for performing clinical procedures). The effective application of physics in clinical procedures requires more complex knowledge structures in the brain, specifically the development of mental sensory concepts, which are different from developing a collection of symbolic knowledge elements, including verbal descriptions, definitions, mathematical symbols, equations, and quantities. That has been described in previous publications included in the bibliography. An overview is provided in Figure 8.

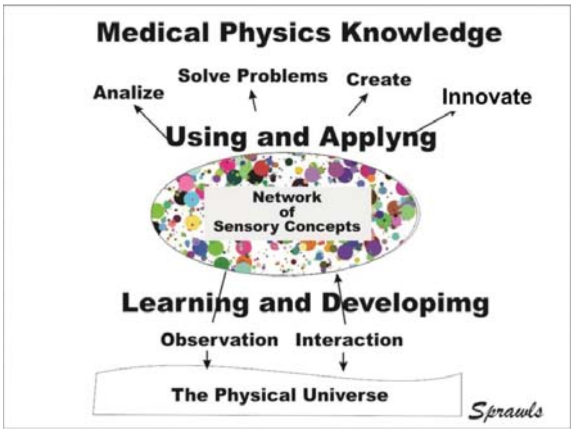

Fig.8. The significance of conceptual knowledge in medical physics education, the link between learning and applying.

The significance is that medical images are physical objects with specific physical characteristics. Sensory concepts are the necessary mental knowledge structures for clinical physics characteristics and related factors.

The two necessary actions required for the development of useful sensory physics concepts as illustrated in Figure 8 are *observation* and *interaction.* This can be a progressive process beginning with class and conference discussions with physicists and followed by interactions between residents and the imaging procedures and interoperations guided by experienced radiologists.

The medical image is the unifying object among the clinical sciences: applied physics on one side and the biological sciences of the human body on the other as illustrated in Figure 9.

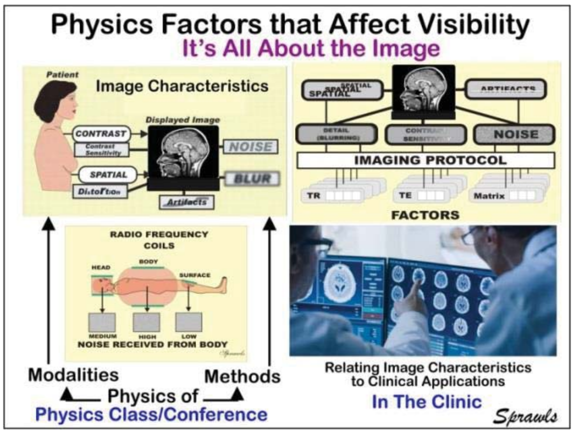

Fig.9. Unifying the physics classroom with clinical applications using the image as the interface.

VII. CLINICAL IMAGES FOR PHYSICS EDUCATION

The clinical practice of radiology and radiology education is based on images. Residents learn about medical imaging by viewing and studying images. This is well established in clinical radiology and is the opportunity for more effective physics education within residency programs.

Clinical Teaching Files

Major resources for residency education are the "teaching files" with extensive collections of images covering the range of pathological conditions as visualized with the different imaging modalities' and methods. The files relate the images to conditions within the human body and the procedures used to produce the images. Every institution has its teaching files that have been developed over time. There are also excellent teaching files provided online by radiology organizations and institutions. The clinical teaching files are often used for individual study by residents and are also a valuable source of images for class and conference discussions.

Physics Teaching Files

Effective image-based teaching files for physics will contain images that illustrate the range of physical characteristics, especially those affecting visibility, how the images are produced, and the relationship to the many factors that determine and can be used to adjust image characteristics. The goal is for physics classes to have the resources to, in effect, simulate the clinical imaging procedures where physics educators can demonstrate and discuss the physics of images that apply to and are encountered in clinical practice. This would consist of a collection of images for each modality produced with the range of imaging factors that affect characteristics, object visibility, and related factors such as radiation dose. An example: for mammography this includes images produced with different x-ray spectra determined by the KV and filter combinations. For MRI it is even more complex because of the many adjustable protocol factors that affect image characteristics. As of now, such a complete and available physics teaching file does not exist. The clinical teaching files used by radiologists consist of images collected from routine clinical procedures. However, a complete physics teaching file needs images over a range of imaging conditions such as KV values. These are not available from routine clinical images and not appropriate to produce on living humans because of radiation exposure, unnecessary examinations, and other limitations. It is possible to produce multiple images on phantoms that demonstrate effects of imaging methods and factors on image characteristics and visibility, but they do not provide the desired connection of physics to clinical radiology as images of the human body. Artifacts are one image characteristic where examples can be collected from clinical procedures.

Local Physics Teaching Files

The effort now is to include images as the major object in physics education for residents and radiologists as illustrated previously. Individual physics educators can develop their image teaching files with images from within their institution and in collaboration with clinical colleagues. However these will be limited in scope with respect to the range of imaging conditions.

The Internet

A major source of images for teaching is the internet and world-wide-web (WWW). Many institutions, professional organizations, and medical imaging equipment manufacturers have posted extensive collections of images. These can be located by using Google Image search at: https://images.google.com/ and entering a term to search, like "mammograms." Give it a try.

The Sprawls Resources

The Sprawls Resources on the web at http://www.sprawls.org/resources/ is a comprehensive collection of visuals, modules, and textbooks that are available as an open and free resource for medical physics education, especially for residents in radiology.
A major feature is that the physics curriculum is structured around images as the beginning point and principle focus for the physics educational activities.

Simulations

Because a complete collection of images for teaching physics cannot be obtained from routine clinical procedures or additional imaging of living humans, other methods must be developed. Computer based simulations are a potential source for images demonstrating many image characteristics and related factors. The general "photo" image processing programs can be used to produce images with different contrast characteristics, detail (resolution), and noise characteristics and demonstrate effects on visibility within clinical images. There is the potential for developing more complex computer-based simulations of various imaging procedures with which factors can be changed and the effects on image characteristics observed.

Simulated images for teaching physics can be used in several forms. A series of individual images can be included in Power Point preservations or in a web-based simulation that can be projected and interacted with during physics classes and discussions. An example is on the web at: http://www.sprawls.org/thelab/ .

The various simulation methods can be used to produce highly effective images for physics teaching files, but they require considerable effort and resources for individual physicists to produce for their teaching.

Collaborative Teaching, Sharing Resources, And On to the Future

There is now the opportunity for medical physicists to collaborate by producing images on specific topics and then sharing them on the internet for all to use. It is a practice that radiologists use for clinical images. The online sharing of clinical images for teaching and study is encouraged and supported by the major radiological organizations including the RSNA and ACR. Both provide capabilities for posting and sharing images on their websites.

A physics image teaching file was developed by the ACR as a component of the extensive clinical teaching file that was printed and distributed on x-ray film, before the time of digital radiography. In 2005 these films were digitized and posted online by the AAPM for members to use. As of now none of the medical physics organizations provide opportunities for individual medical physicists to post and share clinically related images they have collected or produced. That can be a project for the future.

VIII.SUMMARY AND CONCLUSIONS

Images are physical objects that are the foundation of radiology. They are the interface between clinical medicine and physics. The effective practice of radiology requires a comprehensive knowledge of the traditional biological sciences and the physics of images, including their characteristics, methods of production, and factors affecting visualization of clinical conditions. Physics education within radiology residency programs has two major but often conflicting learning objectives. The first and short-term is preparation for certifying examinations. The other and more long-term (professional life-time) is applying physics knowledge in the practice of clinical radiology. Sources of the conflict include different knowledge structures (symbolic or conceptual) to meet the different objectives, interests and motivation of residents, and demands on physics educators to "teach-to-test," either directly or implied.

A reality is that physics education that begins with and is structured around images can meet both objectives and overcome some of the conflicts. Learning the physics of images and imaging procedures is a continuing process. It begins in the class/conference room with medical physicists using their knowledge and experience to guide residents' observation and analysis of images and understanding of relationships to methods and procedures. With this physics class foundation the clinical activities provide an opportunity for additional learning and applying physics concepts and principles to the process of producing and evaluating optimized images.

The continuing enhancement of physics education for radiology residents structured on images and their physical characteristics requires an extensive collection of images for teaching, similar to the well-established clinical teaching files used by radiologists. This need can be met by individual medical physicists developing and sharing images for teaching on specific topics.

Models of the learning and teaching process as developed by three pioneers in the field of education, Blume, Dale, and Gagne, provide guidance for developing physics educational activities for radiologists.

IX. BIBLIOGRAPHY

The following publications by the author provide additional information and background on physics education applied in clinical radiology.

1. Effective Physics Education For Optimizing Ct Image Quality And Dose Management With Open Access Resources. P. Sprawls1, P-A. T. Duong, MEDICAL PHYSICS INTERNATIONAL Journal, vol.1, No.1, 2013 http://www.mpijournal.org/pdf/2013-01/MPI-2013-01-p046.pdf

2. Physics Education For The Optimization Of MRI Clinical Procedures: Visualizing The Invisible And Collaborative Teaching. **P.** Sprawls. MEDICAL PHYSICS INTERNATIONAL Journal, vol.1, No.2, 2013 http://www.mpijournal.org/pdf/2013-02/MPI-2013-02-p134.pdf

3. Optimizing Medical Image Contrast, Detail And Noise In The Digital Era.
P. Sprawls. MEDICAL PHYSICS INTERNATIONAL Journal, vol.2, No.1, 2014 http://www.mpijournal.org/pdf/2014-01/MPI-2014-01-p041.pdf

4. Education Models For The Expanding Role Of Clinical Medical Physics.
P. Sprawls. MEDICAL PHYSICS INTERNATIONAL Journal, vol.5, No.2, 2017 http://www.mpijournal.org/pdf/2017-02/MPI-2017-02-p167.pdf

5. Developing Effective Mental Knowledge Structures For Medical Physics Applications.
Sprawls, P. MEDICAL PHYSICS INTERNATIONAL Journal, vol.6, No.1, 2018 http://www.mpijournal.org/pdf/2018-01/MPI-2018-01-p128.pdf

6. Digital Elements, Image Quality, Radiation Exposure, And Procedure Optimization**.**
Perry Sprawls. MEDICAL PHYSICS INTERNATIONAL Journal, vol.6, No.2, 2018 http://www.mpijournal.org/pdf/2018-02/MPI-2018-02-p255.pdf

X. ADDENDUM

Clinically Focused Physics Education
Visuals for study, discussion,
and in presentations

See p. 361

XI. ACKNOWLEDGEMENT

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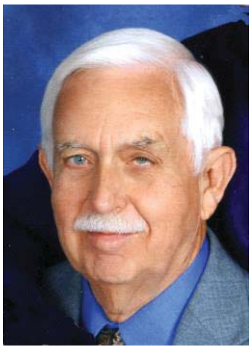

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