MEDICAL PHYSICS *International*

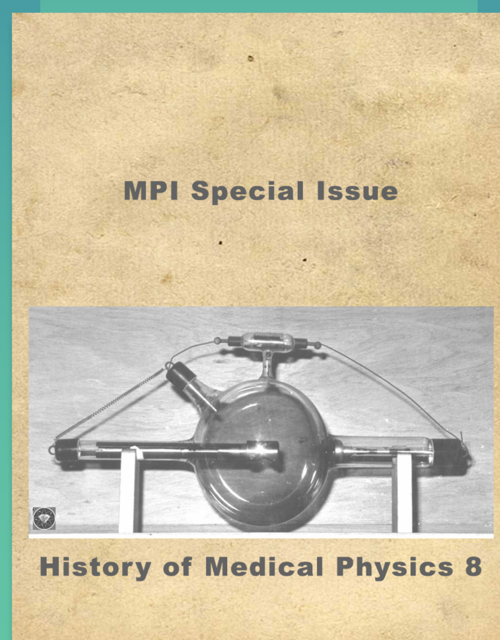
Editorial

HISTORICAL EVOLUTION OF PHYSICS CLASSROOM LEARNING AND TEACHING

A BRIEF HISTORY OF FRACTIONATION IN EXTERNAL-BEAM RADIOTHERAPY

MEDICAL PHYSICS FOR THE USE OF STUDENTS AND PRACTITIONERS OF MEDICINE By John Draper

MONUMENT TO THE X-RAY AND RADIUM MARTYRS OF ALL NATIONS



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The Journal of the International Organization for Medical Physics

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EDITORIAL

Slavik Tabakov, Perry Sprawls and **Geoffrey Ibbott**
MPI Special Issues Co-Editors

This Special Issue includes specific articles on the history of Fractionation in External-Beam Radiotherapy; the historical development of Medical Physics education delivery, one of the first books on medical physics from 1885 and others. Medical Physics is a dynamic profession constantly advancing with innovations and developments in technology, scientific methods, and clinical applications. The profession as we now know, practice, and teach it, has a rich history and heritage that is its foundation. This is the foundation built by many pioneers and collaborating physicists whose vision and efforts led to the development of medical physics as we know it today. As we read and reflect on the historical events described in this Edition it might be interesting to think of ourselves in their position, both time and available technical resources, and how we might have advanced the practice of medical physics.

We are very happy to see that the overall popularity of the History Project is growing - each MPI Special Issues has over 10,000 downloads. This is a clear indication of the value that the profession sees in the project. All of the medical physics history articles can be accessed through: http://www.mpijournal.org/history.aspx

The History topics extensively covered in MPI so far include:

<u>Special issue 1</u>- http://www.mpijournal.org/pdf/2018-SI-01/MPI-2018-SI-01.pdf

*X-ray Tubes Development; *Film-Screen Radiography Receptor Development; *History of Medical Physics e-Learning Introduction and First Steps

<u>Special issue 2</u> - http://www.mpijournal.org/pdf/2019-SI-02/MPI-2019-SI-02.pdf

*Fluoroscopic Technology from 1895 to 2019; *The Scientific and Technological Developments in Mammography;

*Review of the Physics of Mammography

<u>Special issue 3 - </u>http://www.mpijournal.org/pdf/2020-SI-03/MPI-2020-SI-03.pdf

*History of Dental Radiography ; *The History of Contrast Media Development in X-Ray Diagnostic Radiology;

*Medical Physics Development in Africa

<u>Special issue 4 - </u>http://www.mpijournal.org/pdf/2020-SI-04/MPI-2020-SI-04.pdf

*A Retrospective of Cobalt-60 Radiation Therapy; *The Many Steps and Evolution in the Development of Computed Tomography; *Medical Physics Development in South-East Asia; *History of Medical Physics Education and Training in Central and Eastern Europe

<u>Special issue 5 - </u>http://www.mpijournal.org/pdf/2021-SI-05/MPI-2021-SI-05.pdf

* Ultrasound-the First 50 Years;*Measurement of Acoustic Pressure and Intensity Using Hydrophones;* Measurement of Acoustic Power and Intensity Using Radiation Force; *Thermal Methods for Ultrasound Measurement development

<u>Special Issue 6</u> - http://www.mpijournal.org/pdf/2021-SI-06/MPI-2021-SI-06.pdf

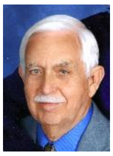
*History of Medical Ultrasound-Imaging; *The Diasonograph Story; *Hewlett Packard - Innovations that Transformed Diagnostic Ultrasound Imaging; *History Of Doppler Ultrasound; *A History of HIFU Therapy

<u>Special Issue 7 - </u>http://www.mpijournal.org/pdf/2022-SI-07/MPI-2022-SI-07.pdf

* IOMP HISTORY – Activity Development and Main Documents (3 papers 1960-2022); IOMP HISTORY TABLES

Additionally, history information about the development of medical physics in all continents can be seen in the Regular issues of MPI 2019-2021, where all IOMP Regional Organisations included papers about the professional and educational development in many of the countries within their geographical areas. The content of the Special History Issues of the Medical Physics International (MPI) Journal supports the objective of the History project: to research, organize, preserve, and publish on the evolution and developments of medical physics and clinical applications that are the foundations of our profession. We welcome contributions of colleagues from all societies, organizations and companies who would like to join the History project with articles on specific topics. We look forward to receiving your suggestions.


Prof. Slavik Tabakov


Prof. Perry Sprawls


Prof. Geoffrey Ibbott

IOMP PROJECT HISTORY OF MEDICAL PHYSICS

(SELECTED CHAPTERS)

HISTORICAL EVOLUTION OF PHYSICS CLASSROOM LEARNING AND TEACHING

A Personal Perspective and Journey

Perry Sprawls
Emory University, Atlanta and Sprawls Educational Foundation (www.sprawls.org)

Contents

1. Introduction

The *classroom* has been the space for teaching and learning throughout the centuries and continues as a vital component of physics education now and into the future. The major purpose of a classroom is to bring together two parties, *students,* and *teachers*. The students, the class, are there to learn or develop mental knowledge structures of specific topics. The teacher, the educator, is there to help and enhance the learning process through several activities. This can occur in many forms ranging from *verbal lectures* in which the teacher talks about what he or she knows to *leading a highly effective interactive learning activity* with physical or visual representations of the physical universe being studied. The significant is the type and characteristics of the teaching determines the type and ultimate value of the knowledge developed by the students and how it can be used to support future activities, especially as practicing physicists or other professions, especially medicine in which physics is a fundamental science.

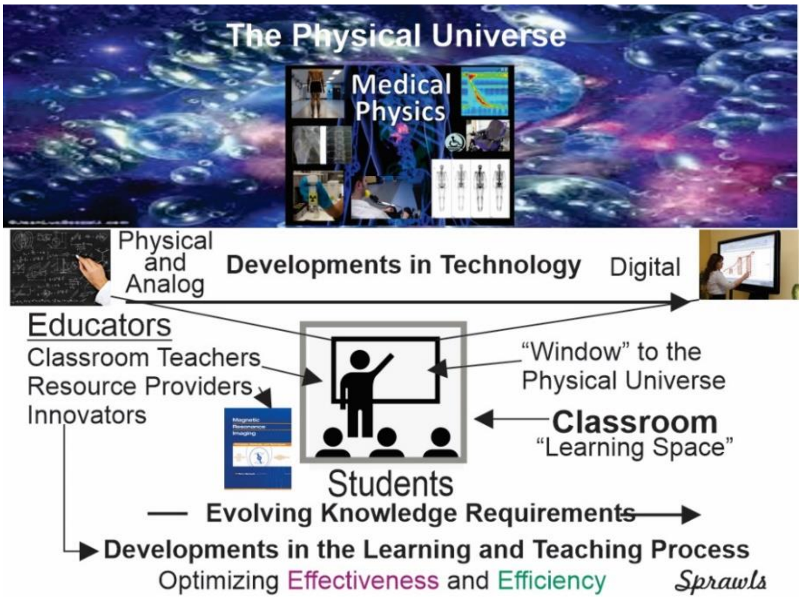
Classroom teaching and learning, especially for physics, has evolved through a series of developments during the 60-year period (1960-2020) that is considered here. A major factor has been the developments in technology, ranging from a piece of chalk and a blackboard to digital technology and the World Wide Web. In most fields of physics, and especially medical physics, the scope and complexity of the diagnostic imaging and therapy technology and physics applications has "exploded" requiring major developments in the educational process and classroom activities to meet the needs of the professionals.

During the approximately 60-year period considered here, there have been at least ten (10) distinct eras, most defined by the developments and available technology. There are two (2) often conflicting characteristics of classroom learning activities that impact the continuing evolution. One is the *effectiveness* in the development of useful knowledge and the other is the *efficiency* with respect to the effort, cost, and resources required.

From my personal perspective the two major advances have been adding "windows" to physics classrooms to visually connect students to the physical universe and the development of "collaborative teaching" as will be discussed later.

The period considered here, 1960 – 2020, generally corresponds to my classroom teaching career in which I have experienced and, in some cases, hopefully participated in the *Historical Evolution of Physics Classroom Learning and Teaching.*

There are many elements in the continuing development and evolution of the physics classroom as a *space for learning and teaching* as illustrated below.



These are some of the factors that will be considered as we follow the evolution of classroom activities to meet the expanding needs for *physics knowledge*, especially in the field of medicine.

There are two distinct components of classroom function, *humans* and *technology*. While the development and dramatic expansion of technology has brought major advances to the classroom, technology continues to be the "tool" that can be used by the humans, both students and teachers, for much more effective and efficient learning experiences.

It is the human teacher that uses their knowledge, experience, and available technology to help students learn and develop appropriate and valuable knowledge structures. The classroom, both as a physical room, or a virtual world-wide network maintains it longtime purpose, bringing together, students and teachers.

2. In the Beginning

Although classrooms have been at the center of learning and teaching for centuries, here we are considering a recent 60 year period in which the extensive evolution of the classroom has occurred. The story begins in 1960 when I joined the Emory University faculty in Atlanta as a young physics instructor as illustrated in Figure 1.

Figure 1. The author's first classroom equipped with a blackboard and a few pieces of chalk for writing and drawing.

A classroom with a blackboard and chalk was standard in most institutions around the world as it had been for centuries. It was the type of classroom in which many of us received our education and began our teaching careers. It provided us with what we needed to teach as "we had been taught" by lecturing and drawing or writing on the board.

As a young physics teacher standing before a large class, I was overwhelmed with the thought, how am I going to help these students learn about the ***great physical universe*** *out there when we are completely separated from it and enclosed in this classroom, that I began to describe as "****dull box without windows****" and all I had was a blackboard and some pieces of chalk?*

That challenge was to motivate my efforts throughout the next 50+ years to develop "classroom windows" through which students could view and interact with the many details of the physical universe, especially medical physics, and teachers could more effectively guide the learning process. That ongoing and continuing process involves a combination of many factors including the expanding needs for physics knowledge for clinical applications, the research and development of models for the learning and teaching process by several innovators, and especially the continuing developments and applications in technology. My personal experience over the years provides the background and perspective for reviewing the many developments and evolution of the physics classroom and especially the impact on medical physics education today.

3. Learning and Teaching

There are two specific activities that occur in classrooms, *learning* by the students and *teaching* by the professional educator, generally designated as the teacher. The quality of learning by students, both in content and types of mental knowledge structures depends heavily on the abilities and actions of the teacher and technological resources available in the classroom to enhance the learning process.

Learning

Learning is generally defined as the acquisition of knowledge or skills through experience, study, or by being taught. It is a *natural mental function* that occurs within the human brain. It is a highly complex process with ongoing research in several scientific disciplines.

For those of us who are medical physics educators some less complex but verified models of the learning process as described later provide what we need to know to develop and conduct effective classroom learning activities.

Teaching

Teaching is what we as educators do or attempt to do in the classroom. It can occur in many forms often depending on the subject being taught, the needs of the students, the available resources, and the knowledge, experience, and motivations of the teacher. It can range from just speaking and lecturing to leading multi-sensory interactions with the physical reality or representations of reality, especially images.

The Challenge

For me there was an immediate challenge. How was I, the teacher, to connect and teach my students about the extensive physical universe when we were enclosed in a room and the only things, we could see were walls and a blackboard on which I could write and draw.

Classrooms with blackboards were the standard in schools, including colleges and universities, and were considered adequate for teaching many subjects with lectures and words and symbols on the blackboard. Subjects including history, literature, and mathematics.

The great limitation and challenge were in teaching the sciences and medicine in which mental knowledge structures other than facts, definitions, verbal descriptions, and symbolic representations and relationships were needed. What students needed was conceptual knowledge and sensory, generally visual, representation of the physical universe

4. Mental Knowledge Structures for Physics

The major purpose of classroom teaching is to help learners/students develop knowledge, generally to fulfill their specific needs relating to how they will use the knowledge in the future. Knowledge of physics, including medical physics is a mental representation of segments of the physical universe within the human brain as illustrated in Figure 2.

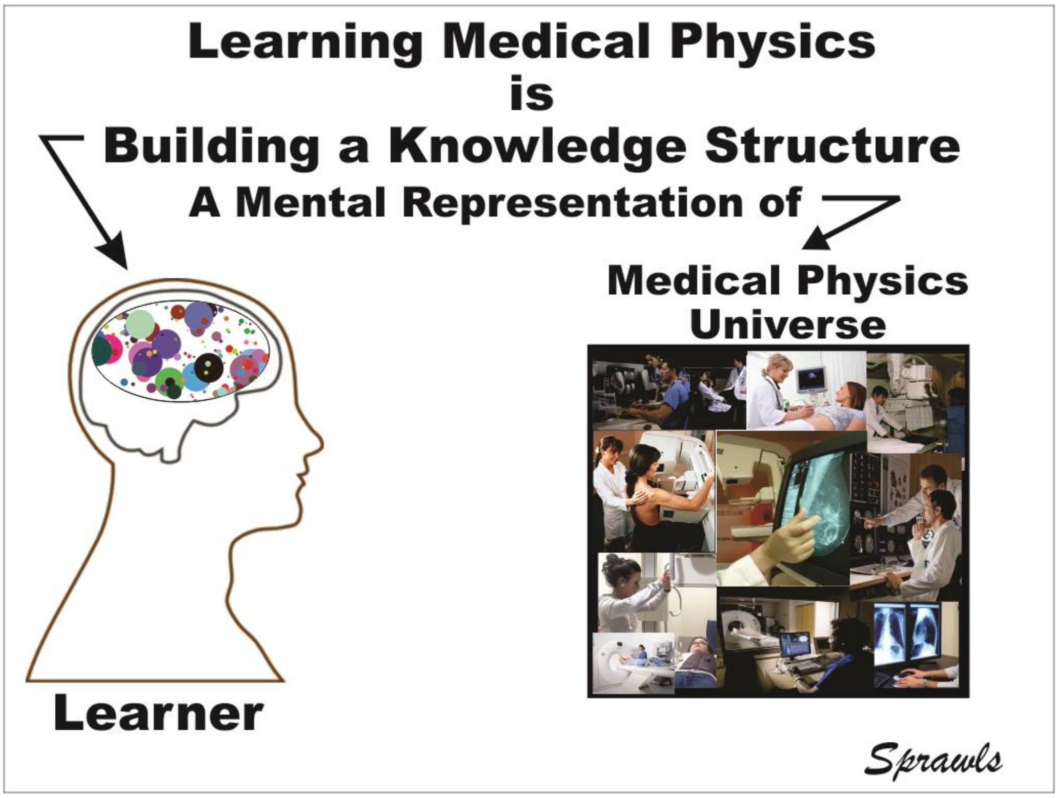


Figure 2. The concept of physics knowledge as a mental representation of the physical universe.

The development and preservation of knowledge within the brain is a complex process. With respect to physics, it is helpful to consider two major types of knowledge structures, *sensory concepts* and *symbolic* (words and symbols). Both are valuable and enables the learner to perform specific functions.

Physics is a highly quantitative science and the symbolic representation with mathematical symbols and equations is the type of knowledge needed for many functions including analysis and evaluation where quantitative values (radiation dose, image blurring, etc.) are required. It also provides an understanding of the many quantitative relations among physical quantities; Ohm's law is an example. Physics knowledge in the form of mathematical equations and ability to make calculations has value for many functions but is not the knowledge needed to understand and manage the physics in applications, both in our daily lives and professionally. This requires physics knowledge in the form of *sensory concepts.*

The distinction between these two knowledge types, symbolic and conceptual, is a major factor in providing effective classroom learning activities.

Learning Physics

Learning physics is an ongoing natural human process (along with breathing, eating, etc.) as we experience the physical world around us that begins soon after birth and long before we begin school and organized education. Consider our learning the physics of water, a major component of the physical universe as illustrated in Figure 3.

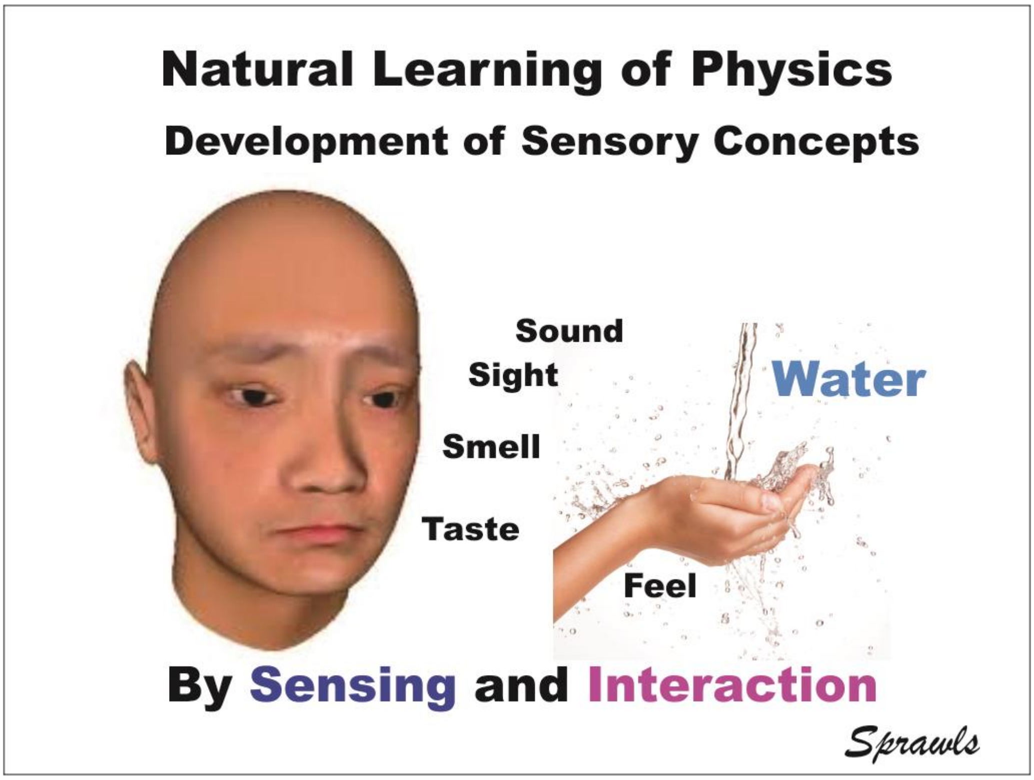


Figure 3. Learning the physics of water.

The physics we learn naturally throughout life, like the physics of water, has several valuable characteristics that can guide us in developing more effective classroom learning activities in medical physics.

- It is learned through *observation* and *interaction* with a segment of the physical universe.
- The knowledge gained through observation and interaction can be enhanced with *guidance* from others with experience, parents, swimming couches, etc.
- It is valuable knowledge that can be *used in many future activities* involving water, as a beverage, cleaning, sports, and much more.

Through this natural process we learn many other branches of physics including mechanics (toys, sports, work projects), optics (sight and use of lens), acoustics (music and entertainment) , and often some electricity and magnetism.

Knowledge Characteristics, Types and Levels

A contributing factor to the historical evolution of classroom learning and teaching has been the research and development of conceptual models of the organization and characteristics of knowledge within the human mind. One that has been used extensively in the development of educational methods and activities is provided by Bloom in the form of a taxonomy and illustrated in Figure 4.

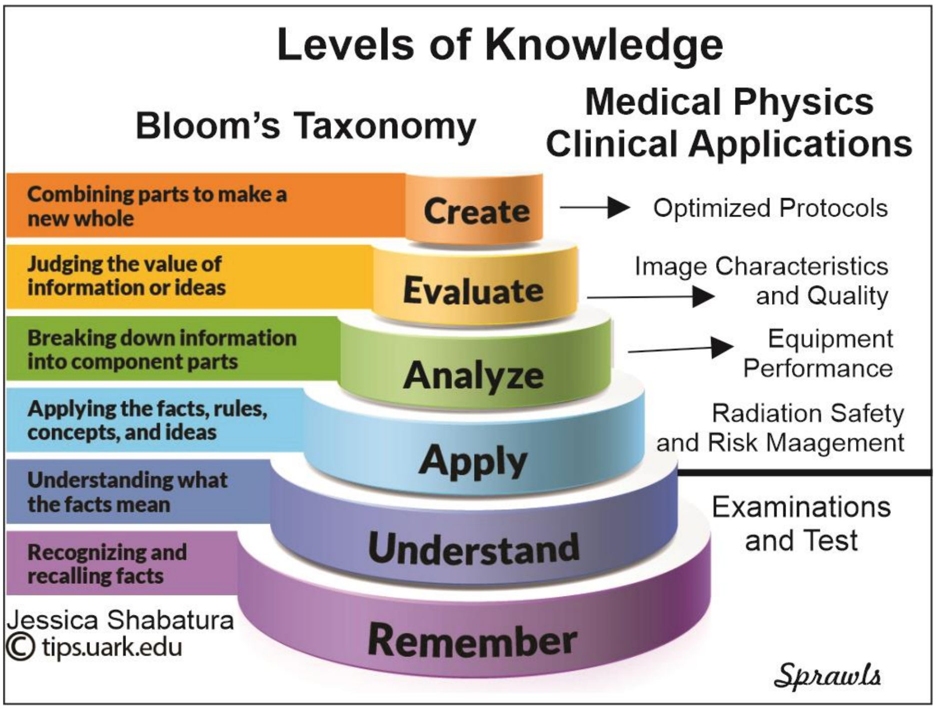


Figure 4. The levels of knowledge as defined in Bloom's Taxonomy with example medical physics applications provided by the author.

Bloom's taxonomy is an organization and classification of different knowledge types into levels generally relating to complexity. Each level is associated with specific functions or activities requiring that type of knowledge. It is named for Benjamin Bloom who led the group of educators who developed the taxonomy and edited the first book, *Taxonomy of Educational Objectives: The Classification of Educational Goals*. This, and later revised editions have been used in the development of learning objectives, testing, and teaching methods and activities.

As illustrated in Figure 4, there are different types of knowledge needed for specific medical physics functions. The significance is educational activities, including classroom teaching must be designed and delivered to help learners develop the required knowledge.

With this background of learning physics, we can now consider the classroom in its role of physics education. This includes value and advantages it brings along with its major limitations and challenges.

5. Effectiveness and Efficiency of Learning and Teaching Activities

Any learning activity, and especially those in classrooms have two major, and often conflicting characteristics, *effectiveness*, and *efficiency*. These are major factors that have driven the continuing developments and evolution of physics classrooms and teaching over the years.

The Purpose and Efficiency of the Classroom

Our interest and subject of this article is *classroom learning and teaching* and specifically the evolution over the course of recent history. Let's consider the major purpose of a classroom. It is a place for bringing together a group of learners/students, the class, and bring them into a relationship with a teacher. There would be other ways of connecting students and teachers, for example one-to-one tutoring but the classroom provides one major value, *efficiency*. It provides one person the ability to connect with and teach a large class of students as illustrated in Figure 5.

Figure 5. Illustration of the efficiency of a large class being taught by one faculty member.

That is the major value and purpose of classroom teaching. Another factor affecting efficiency are the methods used for presenting the topics to the class. At the top of the list with respect to efficiency is lecturing, a verbal description and explanation of a topic, often with some form of visual illustrations. This has been the predominate form of classroom teaching for many subjects over the years.

The Effectiveness of Classroom Learning and Teaching

The prevailing issue with any learning activity, and especially in the classroom is the *value of the knowledge* developed by students, what can it be used for. That is how *effective* is the knowledge in preparing for specific functions and activities. Within the field of medical physics there are many different functions to prepare for, especially with the expanding clinical applications.

Preparing medical physicists and related medical professionals, especially radiologists, to use physics knowledge to enhance both diagnostic imaging and therapeutic medical procedures is a continuing educational challenge, and especially with classroom teaching. Classroom methods and activities that can be *effective* in producing appropriate knowledge for clinical applications are generally not *efficient* in terms of human effort by the educators and availability of learning and teaching resources.

The effectiveness and efficiency of conducting a learning activity, or teaching a class is related to how the physics topics are presented to the class, or how the class is connected to the physical universe they are learning about. Edgar Dale's model of the learning and teaching process illustrates this relationship as shown in Figure 6.

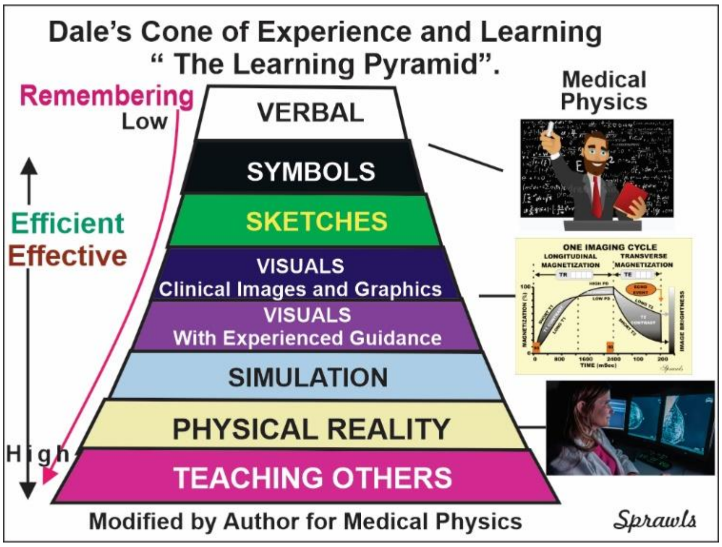


Figure 5. Dales "Cone of Experience" that illustrates relationships among the several characteristics of the learning and teaching process.

The model is constructed on the different methods used to represent the physical universe in a teaching and learning "experience" or activity. This is different from Bloom's taxonomy of the types or levels of knowledge illustrated in Figure 4 but there is a significant relationship that impacts classroom teaching, especially of medical physics, as will explore later.

Learning Activity Characteristics

The different learning activities, or experiences are organized by Dale at different levels based on the type of sensory interaction between the student and subject matter (physical reality) and the teacher. As illustrated, these range from a lecture or verbal description (sound) to multi-sensory observations and interactions at the bottom or base of the cone. This generally corresponds to the degree of abstraction of the representation of the physical reality. From the top to bottom the experiences become less abstract with increasing details conveyed through multi-sensory, especially visual, and physical interactions.

Remembering and Mental Retention

It has been demonstrated that humans remember much more of what they have experienced through multi-sensory experiences and interactions than from just hearing lectures. This is associated with the types of knowledge structures formed within the brain. Mental retention is a significant factor in medical physics education but is not the only value in the less-abstract learning experiences represented by the lower levels in Figure 6. This is what we will now explore.

Effective Learning and Teaching

Hopefully everything we learn has a purpose. Often it is just to broaden our knowledge relating to our interests and activities and the world around us so that we are "better educated". Learning medical physics has two other very specific purposed. One is obtaining good, a least passing, scores on tests and examinations and the other is performing specific physics-based functions and procedures, especially in clinical activities. This is what results in specific *learning objectives* which then determines what and how it is taught in the physics classroom.

The reality is "teaching to the test" and teaching to support the application of physics in clinically related activities generally is conducted through two different types of classroom presentations and activities. It should not be this way but is the result in the limitations of creating tests and examinations that correspond to actual medical physics procedures. Over the years progress has been made in developing examinations, both written and oral, that test for physics knowledge to enable clinical applications but there continues to be considerable separation between the two purposed of teaching.

The *effectiveness* of teaching for applied clinical physics activities generally increases as the learning experiences become less abstract and more visual with interactions represented near the base of the cone as illustrated in Figure 6.

6. Bringing the Physical Universe into the Classroom

Teaching physics requires connecting the learners with sections of the physical universe. These connections can range from highly abstract verbal connections provided with lectures to multi-sensory observations and guided interactions by experienced medical physics educators. Each method is generally characterized by its effectiveness and efficiency. Both are related to the types of knowledge structures that are to be developed by the learners. Considering the two major purposes of learning medical physics, passing examinations and effective clinical applications, there are two types of knowledge structures that are generally used as illustrated in Figure 7.

Symbolic Representations and Mathematics

Physics, including medical physics is a highly quantitative science involving numerical values of the many physical quantities (dose, KV, voxel size, and TR as examples) and mathematical relationships expressed with equations and graphs. Many of the applications of physics in medicine, both diagnostic imaging and radiation therapy require mathematical modeling, calculations, and numerical values on which to make scientific and clinical decisions.

The teaching of physics has often emphasized the quantitative and mathematical representations not only because of its significance and value but because it could be taught with lectures and a blackboard. It is generally how physics has been taught for many years and many of us learned it.

Another factor is mathematical physics is easy to test on examinations. The examinations developed by the teachers, institutions, and certifying organizations and boards establish the knowledge requirements for the learners/students. The result is scores on examinations become the requirements for students with less concern on knowledge for conducting applied physics activities in the future. At all levels from introductory physics to medical board certifications there is the motivation to "teach to the test".

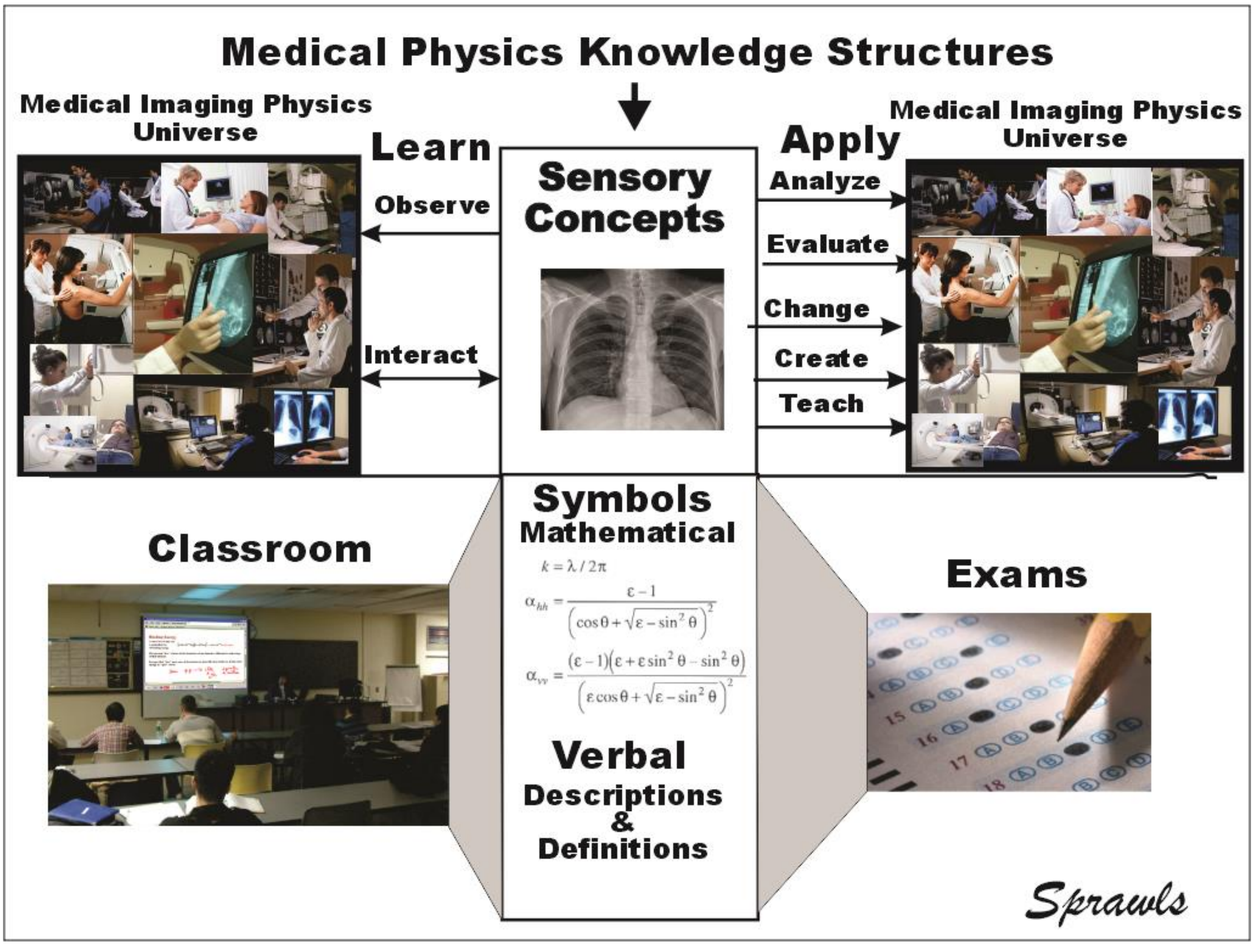


Figure 7. The development and use of different knowledge structures in medical physics.

Verbal Descriptions and Definitions

Verbal, the use of words, to describe objects, people, events, etc. is the fundamental method of teaching with lectures and can be enhanced by writing on boards at the front of the classroom. The resulting knowledge within the learner's mind will consist of memorized facts, definitions, and descriptions in the form of words often without a relationship or understanding of actual physical objects and events.

Verbal knowledge is easy to test for on examinations with a variety of question types including matching, fill-in-the-blank, and discussions. Verbal based examinations along with mathematical based examinations has been the prevalent method for testing physics knowledge for many years. While this knowledge is important in the practice of medical physics it is not the type of knowledge needed for the effect application of physics to both diagnostic imaging and radiation therapy procedures.

Sensory Conceptual Knowledge

Knowledge in the form of concepts, specifically sensory concepts is required to perform many medical physics functions especially clinical activities. Sensory concepts are mental representations of the physical universe formed as we encounter it through our senses (sight, sound, taste, touch, etc.) through our lifetime. It is a comprehensive knowledge including characteristics and relationships of and among physical objects.

The example we are using here and illustrated in Figure 7 is a medical image which is a physical object with many characteristics and relationships to other physical objects and actions. Our useful knowledge of medical imaging physics is formed by visual observation under various conditions associated with the different clinical imaging methods and procedures. It is the type of physical knowledge needed to perform many clinical applications by all professionals, physicists, physicians especially radiologists, and technology.

It is the type of knowledge that cannot be developed in classrooms with lectures and writing boards and symbolic representations. It requires direct sensory interaction between the learner and the physical objects and actions.

The continuing challenge over the years has been bringing the physical universe into the classroom where physics educators use their knowledge and experience to guide learner observations and development of useful knowledge.

7. Collaborative Teaching

T*eaching* is the process of helping someone *learn* and is much more than standing in front of a class and lecturing. Teaching occurs through a variety of activities in which individuals become "teachers" by using their knowledge, experience, talents to help others learn. Authors of textbooks are an example. These have been" teachers" throughout the years providing study materials directly for students and serving as the foundation for many classroom courses. This is an example of collaborative teaching.

With the developments and evolution of the technology-enhanced physics classrooms another form of collaborative teaching has emerged. These are the physicists who create and share visuals that provide windows through which students can connect with and develop valuable conceptual knowledge of the physical universe. *Collaborative Teaching* occurs when high-quality visuals created by one teacher is used in classrooms by another teacher to provide effective learning experiences. The development of digital technology for creating high-quality visuals and the internet for distributing the visuals makes it possible for a physicist in one location to enhance classroom presentations and contribute to the learning and teaching process around the world.

This form of collaborative teaching increases both the effectiveness and efficiency of classroom teaching as illustrated in Figure 9.

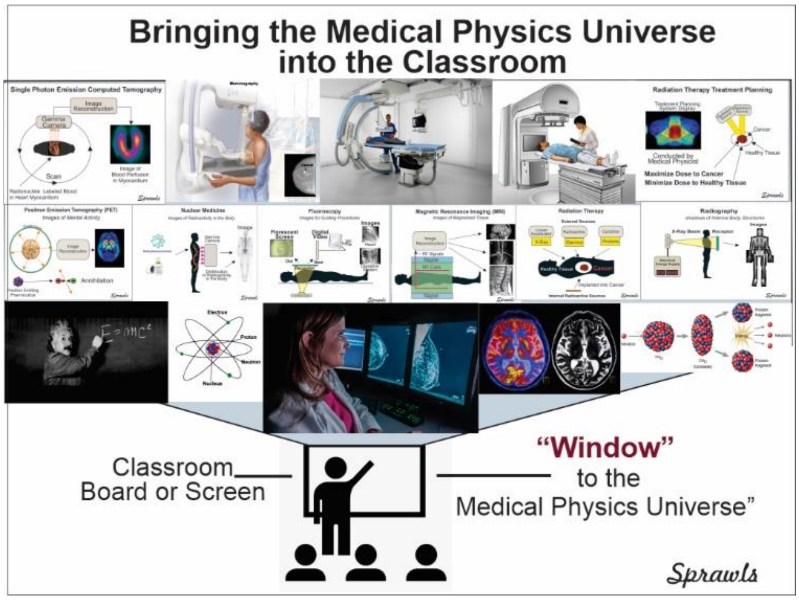


Figure 9. Using visuals as windows to the physical universe.

Bringing the physics universe into the classroom increases the *effectiveness* of the learning activity but requires extensive human effort to create the visuals. The overall *efficiency* of the process is increased when visuals are created and made available for use in many classrooms around the world. That is collaborative teaching.

8. The Classic Physics Lecture

The lecture with blackboard was the established method for teaching physics for years. The capabilities and value of this method was especially emphasized by Richard Phillips Feynman with his famous lecture series illustrated in Figure 10.

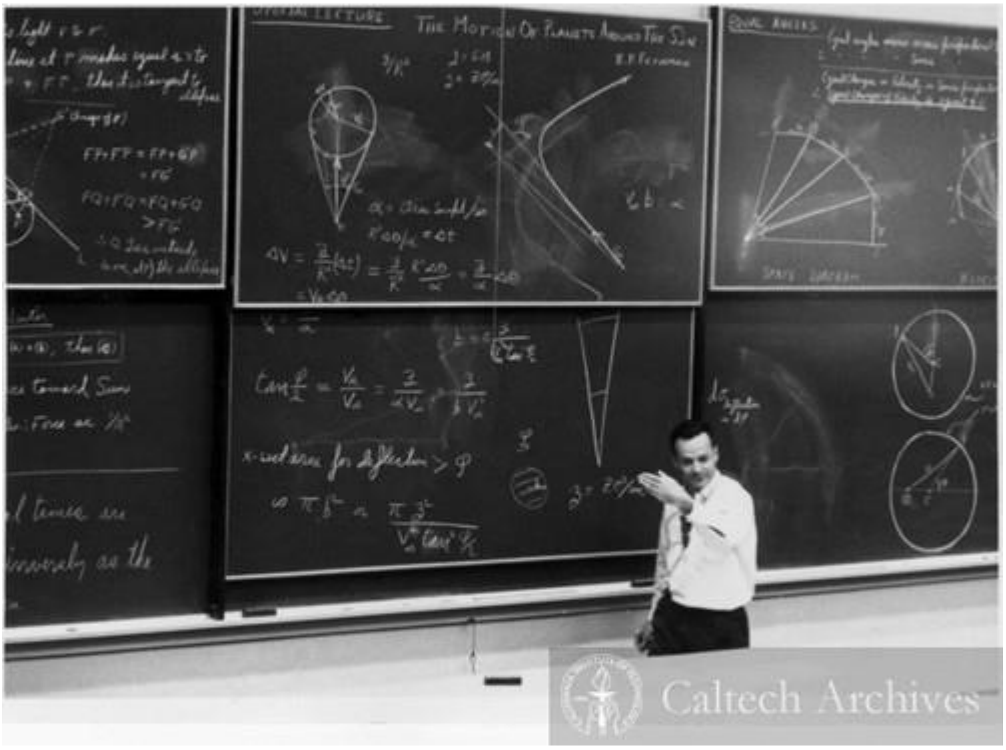


Figure 10. Blackboard illustrations used by Richard Feynman in his physics lectures.

In the early 1960s, Feynman was asked to "spruce up" the teaching of undergraduates at Caltech. This resulted in a series of lectures that later became The Feynman Lectures on Physics that were widely published and valued especially because of the diagrams he used to explain physics.

The technology available to Dr. Feynman (and to me) was a blackboard and pieces of chalk. While Feynman had developed and demonstrated the great value of visual illustrations in forming conceptual knowledge of physics in addition to the symbolic (mathematical and verbal descriptions) there were considerable limitations with respect to the physics educational process…not *effective* for many needs.

One was that the mental images formed by students, if any were remembered, were of the blackboard and somewhat limited sketches…not vivid representations of the physical universe and especially images. The other was each illustration had to be sketched by the teacher, usually while giving the lecture and then erased…very *inefficient*.

The great value of a classroom with blackboard throughout history was it provided the opportunity for a teacher to help a group of students develop knowledge, generally with lectures and writing on the blackboard. The great limitation is the blackboard cannot provide an effective “window” in the classroom for viewing and learning about the physical universe, especially medical physics.

It is now from the classroom with blackboard in the 1960s that many developments and innovations have occurred to increase both the effectiveness and efficiency of physics education and specially to support medical physics clinical applications.

9. Textbooks, Classroom Demonstrations, and Student Laboratories

While classroom teaching is a major contributor to developing physics knowledge by students it is only one component of the learning process. The limitations of the classroom lecture in developing effective knowledge for students can be addressed with the use of textbooks, classroom demonstrations, and associated student laboratories. Before continuing with the historical development of classroom teaching the role of these other learning activities will be reviewed.

Textbooks

Textbooks have been a major component of classroom teaching, especially in physics. Many physics courses are organized and based on textbooks and the lectures often provide discussions of the text material hopefully to help student understanding as they read and study. The mathematical problems, often included with each chapter are valuable for developing the quantitative knowledge of physics and mathematical skills. Solving problems are often included in lecture discussions.

However, one of the greatest values of textbooks, especially in the blackboard era were the visuals and illustrations they provided. At that time these generally could not be displayed in classrooms for discussion. Well before the days of computer graphics and extensive publishing of photographs the illustrations were drawn by hand and many were of exceptionally high detail and quality as shown in Figure 11.

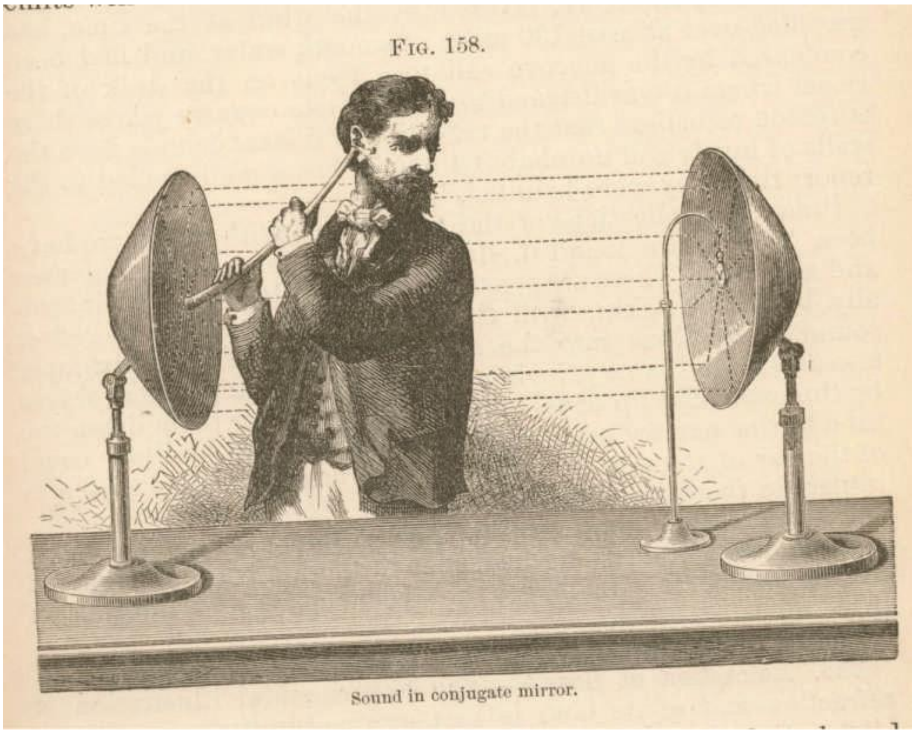


Figure 11. One of the many illustrations from the textbook *Medical Physics* by John Draper, M.D. published in 1885.

It has been illustrations published in physics textbooks that provide visual windows into the physical universe to enhance the learning process beyond symbolic representations. They enable the formation of sensory, especially visual, mental concepts that enable an understanding and application of physics in "real world" events and activities. A great value of textbook illustrations is they are generally created by highly qualified physics educators, the authors, and their professional illustrators, and are of much higher quality than what can be produced by most classroom teachers…especially on a blackboard.

The significant limitations of textbook illustrations were their availability only to those who had the books, and they could not be displayed in classrooms for discussions by teachers. As we will explore later, textbook illustrations became a major element in classroom teaching as a series of image projection methods were developed and evolved.

Classroom Demonstrations

Throughout history one method of bringing the physical universe into the classroom has been with actual physical demonstrations. This was especially common in general physics classes where many of the physical phenomena could be demonstrated with relatively simple and small devices or more comprehensive demonstrations as illustrated in Figure 12.

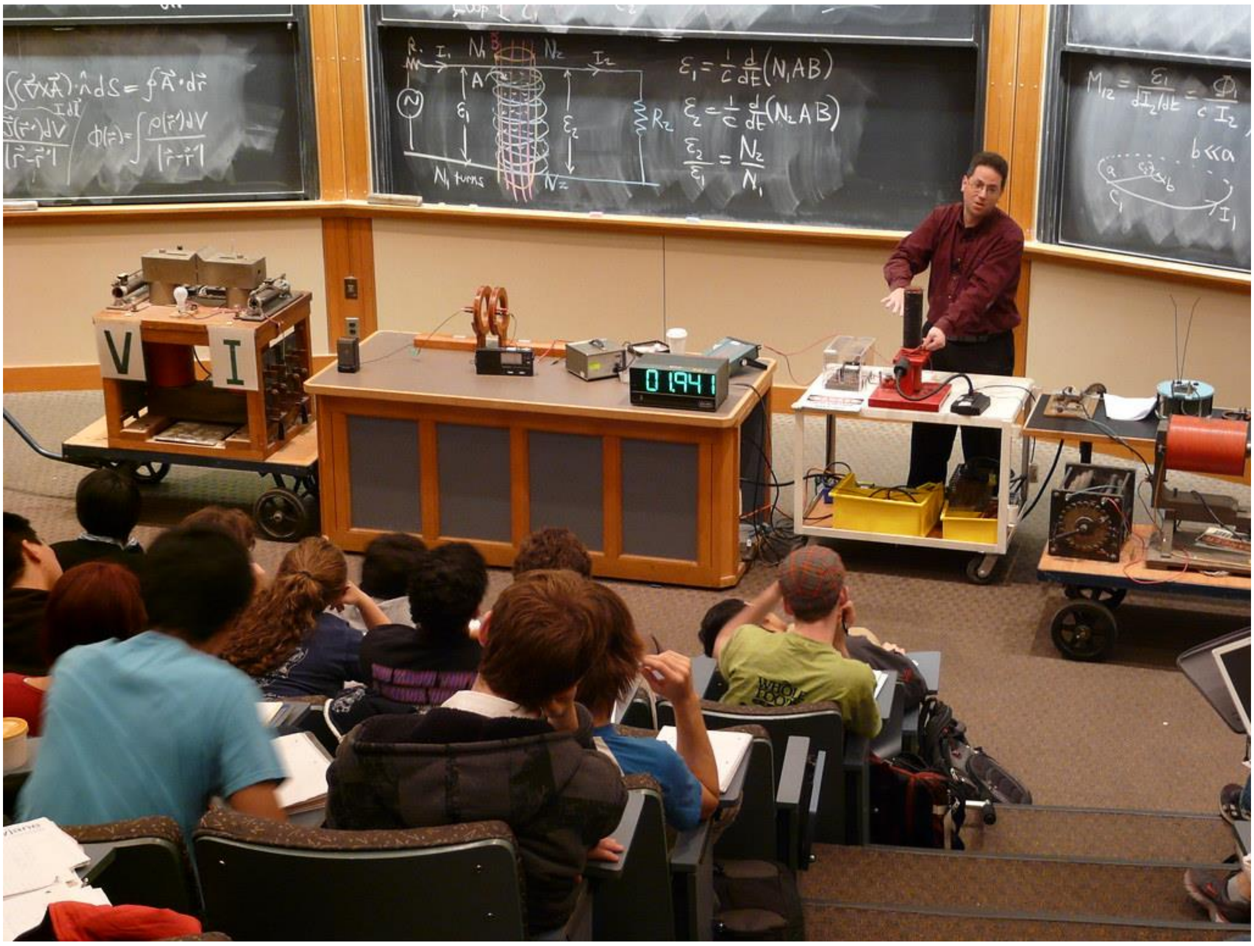


Figure 12. Prof. Winn at MIT augmenting a blackboard lecture with physical demonstrations.

Combining physical demonstrations with blackboard lectures enhances the learning process by connecting the represented theoretical representations with the actual physical universe. Both are valuable in learning physics that can be used in many activities. Many physics departments in institutions around the world had a collection of demonstrations often stored in a room or closet adjacent to the classroom and was a significant element in classroom teaching, especially in the blackboard era before methods for projecting images were available.

The development and use of classroom demonstrations over the years has an extensive and interesting history that is beyond the scope of this article. Our purpose here is to indicate the impact of physical demonstrations on classroom teaching within a historical context with the transition to the expanding impact of projected visuals and images.

To me it is highly significant that our medical physics and radiology professions were introduced to the world with the lecture and demonstration shown in Figure 13.

Figure 13. The presentation by Roentgen on January 23, 1896, describing and demonstrating the use of “a new kind of rays” to image the interior of the human body.

It was the physical demonstration during his lecture that conveyed an understanding and the significance of his discovery and extensive research determining the characteristics and medical applications of the radiation.

Student Laboratories

Demonstrations were valuable in bringing components of the physical universe into the classroom, but they were limited with respect to one significant learning activity, the ability for the student to *physically interact* with the physical objects and functions. This limitation was overcome to some extent with student laboratories that were provided along with the classroom lectures and demonstrations. Laboratory sessions were valuable components of most science and engineering courses, and especially physics which is our interest here.

Laboratory exercises, or experiments were very *effective* in helping students develop conceptual understanding of many physical phenomena (the use of optical lens is an example) but are less *efficient* than classroom lectures for several reasons. For institutions there is the expense of providing space and equipment. A student laboratory generally has a smaller capacity that large classrooms and requires more sessions to go along with one lecture class. Laboratory sessions can require more direct interaction between teachers and students to guide and provide information during the experiments. This is often provided by teaching assistants, perhaps graduate students and not the more experienced classroom lectures. The professors.

Student learning laboratories have been and continue to be a major element in physics education. Figure 14 provides a view of a student laboratory from almost a century ago.

Figure 14. The student physics laboratory at St. Catherine University in 1928.

This illustrates how institutions provided students with the opportunity to observe and interact with the physical universe to enhance their classroom learning and develop more conceptual understanding of physics. Most institutions around the world with physics courses included laboratory sessions often depending on available resources.

A major evolution of student physics laboratories over the more recent years has been a transition from direct interactions with physical devices and equipment to virtual representations and simulations using digital computers as illustrated in Figure 15. These digital laboratory classes were possible with the use of the new digital learning resources – such as the e-books and Educational Image Databases developed by the pioneering projects EMERALD, EMIT and later e-learning projects. These laboratories were especially effective for evaluating image quality parameters using digital images from various modern medical imaging modalities. The computer-based laboratories were also used combined with software for visualizing DICOM images (such as the free ImageJ). During the pandemic situation in 2020-2022 a number of Universities started using online computer-based laboratories.

Figure 15. A computer-based physics laboratory used in the College on Medical Physics program at the ICTP (International Centre for Theoretical Physics) in Trieste, Italy. Dr. Slavik Tabakov is directing the activities.

Computer-based physics student laboratories, especially for medical physics, provide several advantages and values compared to laboratories with physical equipment, efficiency being one. Software has been developed to simulate many physical devices and functions and distributed to be used by many…not requiring multiple sets of equipment. Also, many clinical methods and procedures with physics applications, both diagnostic imaging and therapeutic, use digital technology and methods that can be studied with computer-based laboratories. Perhaps most significantly, are the many clinical procedures and related physics activities that involve images.

10. Learning Physics in the Medical Clinic

Our specific interest is classroom teaching and learning and its evolution over the course of time. And especially the many innovations and developments to provide classroom "windows" through which students can observe and connect with the physical universe. Much of this involves using visual representations, especially images, that can be displayed in the classroom. However, there are times when the physics learned in the classroom needs to be enhanced with learning activities within the clinic. This is not a replacement of classroom learning but generally an opportunity to interactively apply it to develop knowledge that is more effective for performing clinically related functions in the future. This applies to both medical physicists and physicians, especially radiologists.

Practicals for Medical Physicist Students

For medical physics students the knowledge developed in the classroom needs to be enhanced through direct interactions with the clinical equipment they will be working with in the future. It is not practical to have this large and expensive equipment in dedicated student laboratories requiring these learning activities to be conducted in the clinics, often with the challenge of scheduling when the equipment is not being used for clinical procedures…like late evenings and weekends. Consider the practical activity illustrated in Figure 16.

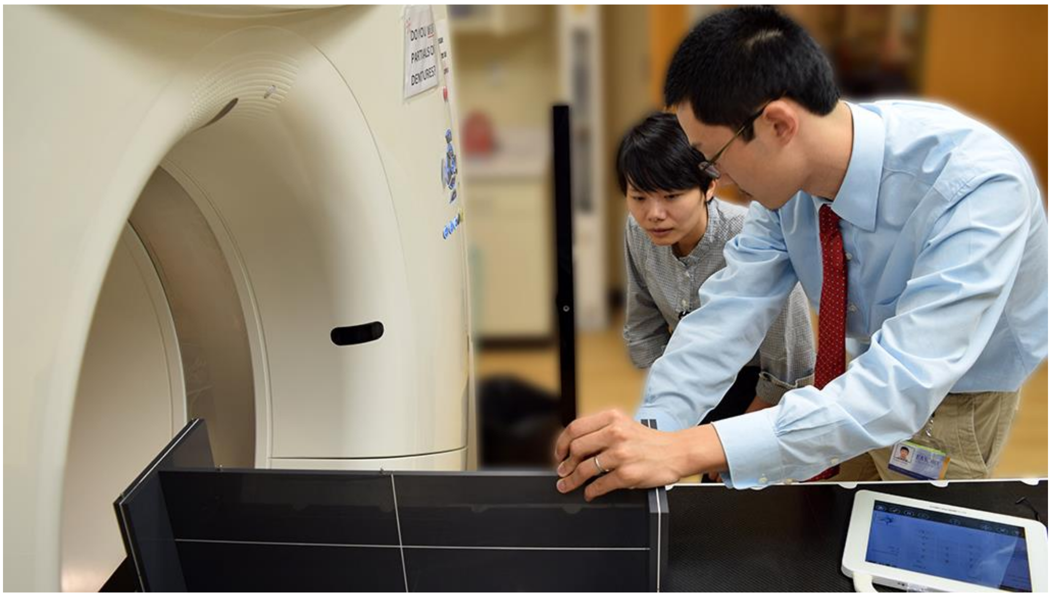


Figure 16. A medical physics practical activity in the Division of Medical Physics, Department of Radiation Oncology Emory University, Atlanta.

The value of a practical activity with clinical equipment includes interactive learning, experience with equipment and procedures that will be worked with in the future, and a direct relationship with an experienced medical physicist teacher.

During the pandemic situation 2020-2022 a number of practicals were recorded on video, transmitted online to students. This helped the students to understand the theoretical value of the lectures. During the more relaxed period of the pandemic period the students were called at small groups to do themselves the practicals.

Physics for Radiology Residents in the Clinic

Beyond passing board certifying examinations Radiology Residents need an understanding of the physical principles of the many diagnostic imaging methods and procedures. This is to enable the evaluation of image characteristics and quality and to optimize imaging procedures for specific clinical needs, mammography is one significant example.

This practical physics knowledge can be developed in the clinic along with learning the medical interpretation of mammograms as illustrated in Figure 17.

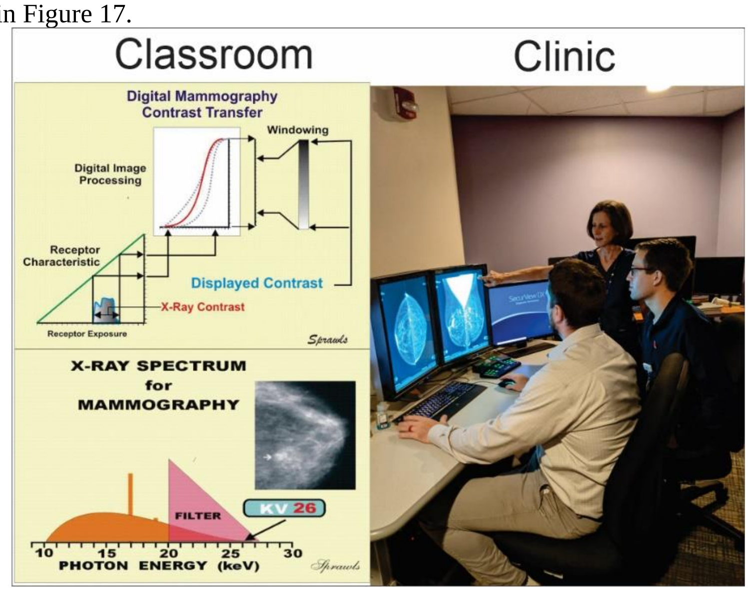


Figure 17. Radiologist Debra Monticciolo, MD discussing the physics of mammograms with residents in the clinic. This is often after reviewing the physics from the classroom presentations and online modules.

Even though student laboratory exercises and practical activities in the clinic provide highly valuable interactive learning opportunities the classroom and conference room continue as a predominate learning spaces for physics. A major factor is the efficiency of bringing a group of students together under the guidance of an experienced teacher with a variety of "windows" to the physical universe through which to observe and develop mental representations of the physical reality. The type and ultimate value of the knowledge is heavily dependent on the characteristics and quality of the visuals displayed and used in classroom presentations and discussions.

It is the development and evolution of the various methods for providing visual "windows" that is the predominate history of the physics classroom over at least the most recent half century. That is now what we will explore.

11. The Evolution of Boards for Writing and Drawing

A common feature of virtually every classroom is a board on which the teacher can write and draw. This was the technology available for providing visual representations of the subjects being taught. The boards have evolved over the years as illustrated in Figure 18.

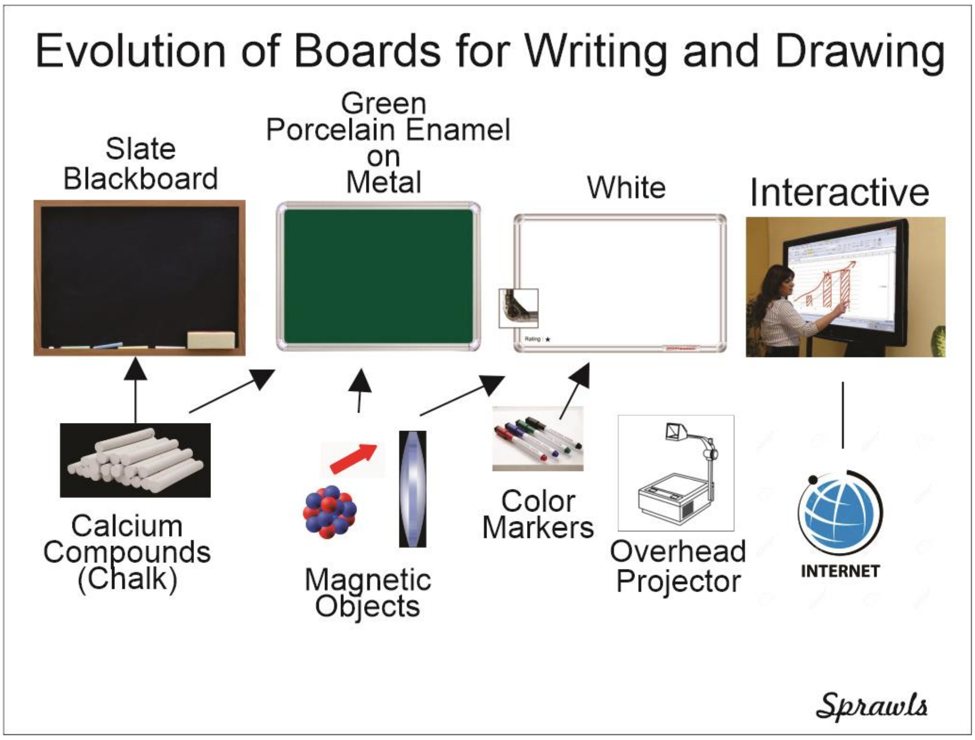


Figure 18. The evolution of classroom boards.

The continuing development and evolution of classroom boards is a major factor on both the *type of physics knowledge* that students could develop in the classroom and the *effectiveness* and *efficiency* of the teacher. It emphasizes the significance and impact of the available technology on the teaching and learning process and the history of the physics classroom.

Blackboards

Up until the 1960s the blackboard and chalk was the available "technology" for providing visual representations of the physical universe in the classroom. The blackboard itself has a long and interesting history (https://en.wikipedia.org/wiki/Blackboard) but it is the use of the blackboard in the physics classroom that we are considering here. Lectures with blackboards was the universal method for teaching physics. Teachers could augment their verbal lectures with symbolic representations (words and mathematical symbols) of the physical universe for very effective presentations, especially for teaching quantitative physics.

There were two major limitations with blackboard teaching that were to be overcome with future developments. One was that the items (words, equations, etc.) had to be written by hand during the lecture, and then erased…not a very efficient process. The major challenge with blackboard teaching was producing effective visuals and images to provide classroom "windows" to the physical universe. This could be done to some extent as illustrated by Richard Feynman in Figure 10. As valuable as these were the images retained in the minds of students were of the blackboard and not the most effective visual representations of physical phenomena, and especially in medical physics.

Greenboards

The evolution to greenboards was more than about color. However, color was a factor in that green is visually more comfortable and less stressful to look at with less glare than blackboards. Writing with yellow chalk on a green board is generally provides more visual contrast than on a blackboard. The green boards were manufactured by coating metal plates with a layer of enamel that was designed to be a good writing surface for chalk.

The green *metal* boards enabled one of the advances in providing visual displays of physical objects in the classroom. Objects with small magnets attached could be placed and arranged on the board to illustrate a variety of physical phenomena and interactions. One of the author's projects in the early 1960s was the development of plastic objects with attached magnets representing atomic particles, vectors, optical elements, and much more to enhance the physics lectures.

White Boards

The end of chalk and dust…the great advantage in the transition to white boards and the use of liquid markers with a variety of colors. Both the black and green boards using chalk for writing and drawing were the source of considerable dust in the classroom and often on the teacher's hands and clothes.

The white boards with the multicolored liquid markers were much easier to erase and clean and opened opportunities for teachers to use a variety of colors. This enabled students to form more detailed mental images.

The availability of whiteboards in the physics classroom and student laboratories was a major development in providing more "windows" to the physical universe, especially with multiple boards on the classroom walls. These are used to display a variety of materials, diagrams, assignments, example calculations, etc. in addition to the board at the front of the classroom used by the teacher during the presentation and discussion as shown in Figure 19.

Figure 19. Dr. Effrosyni Seitaridou uses a whiteboard in a physics class at Oxford College of Emory University.

The whiteboards on the walls of classrooms provides opportunities for students to become more actively involved in class activities by demonstrating their knowledge and understanding.

Another value of whiteboards was they could be used as screens for projected images. They were not ideal for that purpose and had considerable glare compared to screens designed for projected images. Even with this limitation white boards contributed to the introduction of overhead projectors (discussed later) and the effective combination of projected images with drawing by teachers during lectures.

Interactive Boards with Digital Technology

The development of digital technology contributed to the extensive evolution of the physics classroom, as it has for virtually all activities in our society. One specific development was the *interactive board* that combines displayed digital images with the ability of the teacher and students to interact with the images either with fingers or handheld devices. These are also known as interactive whiteboards or smart boards.

Interactive boards are used in a variety of applications including business meeting and conferences and in courses where software programs have been developed to be used in interactive sessions. They have not been used extensively in physics classrooms, especially for upper-level courses including medical physics.

The Values, Limitations, and Evolution of Classroom Boards

A board for writing and drawing by teachers has been a predominate feature in physics classrooms for several centuries. It provides visual displays for students to go along with vocal lectures and physical motions by teachers. A great value is that much about the physical universe requires visual images and cannot be conveyed with spoken words alone. This includes symbolic representations, especially mathematical relationships, diagrams, and images. Especially for physics, the displays on the board are often the most significant information source for students compared to the vocal lectures. The development and evolution of classroom boards from *black* to *white* have provided some advances including the elimination of dusty chalk, better and more pleasing visibility, easier for teachers to use, and increased board space on classroom walls.

A prevailing limitation with all boards is the ability to provide effective visual images of the physical universe to enhance the types of learning needed for physics applications, especially in clinical medical physics. Also, any image or illustration had to be manually produced during the lecture and then erased. That is the limitation that was to be overcome with projected images on screens in the classroom s we will now explore.

12. The Early Projected Images

The major evolution in physics classrooms and conferences, especially in the field of medical physics, was the transition from *boards* for writing to *screens* and projected images. While writing boards continue to serve a purpose in medical physics classrooms it is the projected images that is a predominate source for learning. The methods and technology for producing, distributing, and displaying images in classrooms and conferences have undergone major developments to increase both the effectiveness and efficiency to medical physics education as we will now explore.

The magic Lantern

We do not find these in our physics classrooms now but there are a significant part of our history relating to projected images. *Magic Lantern* was the name given to the first projectors developed for projecting and displaying images on walls or screens. They have a long and interesting history (https://en.wikipedia.org/wiki/Magic_lantern) involving many different versions and innovators. Dutch scientist Christiaan Huygens, is widely accepted as the true inventor of the magic lantern in the 1600s. This was before electrical lighting and the early projectors used candles or oil light sources. They were lanterns that could "magically" make images appear on the wall. The projectors evolved over almost three centuries into the models that were used in classrooms and conferences up into the 1950s as illustrated in Figure 20.

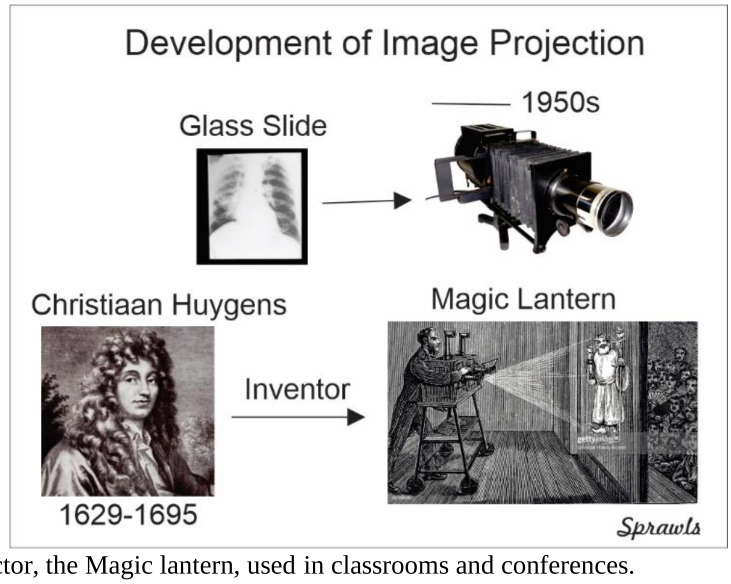


Figure 20. The first projector, the Magic lantern, used in classrooms and conferences.

This projector was not used extensively in physics education, except for conferences especially because of the effort required to produce the transparent glass mounted slides. The medical profession, and especially radiologists found it very valuable for teaching with and about x-ray images. Many physicians developed their personal collection of slides of interesting cases for teaching and conferences.

The Overhead Projector

It was the so-called overhead projector that brought projected *images* into the physics classrooms and conferences. With the projector a page-size transparent image is illuminated from below. A lens and mirror combination mounted above focuses and projects the image onto a screen "over the head" of the teacher as illustrated in Figure 21.

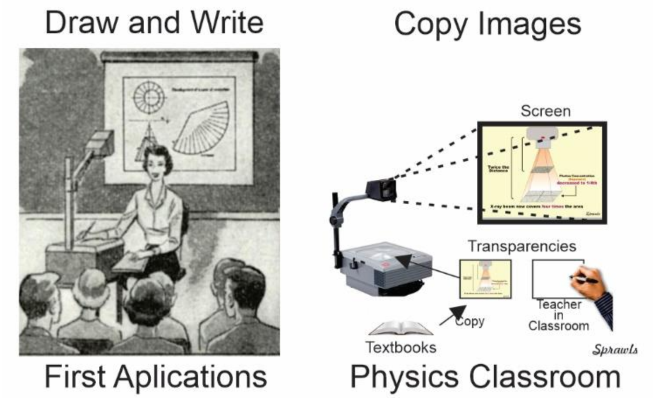


Figure 21. Two methods for producing images for projection.

The overhead projector has a long and interesting history (https://en.wikipedia.org/wiki/Overhead_projector) going back well before its major contribution to physics classroom teaching during the1960 – 70s, when it was the predominate technology in physics classrooms and conferences.

At first the overhead projector served as an illuminated writing board as shown on the left in Figure 21 with everything produced manually as on the large classroom boards. The *equipment* for projecting images by this method has existed in some form for many years it was the development of *transparency materials* that could be printed on with copy or duplicating machines that brought images into physics classrooms and conferences as illustrated on the right. This extended classroom presentations and discussions beyond symbolic representations on boards and verbal lectures and can be considered as the begin of "a New Era" of classroom teaching and conference presentations with images and visuals displayed on screens replacing writing boards and just verbal lectures.

The significance is students can form visual, and not just symbolic knowledge structures of the physical universe and develop more effective and useful conceptual understanding.

The extent to which the overhead projector contributed to physics classroom teaching depended on the availability of images and other visual representations (diagrams, graphs, etc.) on the transparent material. While many teachers produced transparent images manually it was the development of the process of copying and printing on transparent sheets that was the major technological breakthrough generally in the 1960s. Visuals could be copied from textbooks and other printed materials and displayed in the classroom. Teachers could discuss and guide students in developing an understanding and valuable conceptual knowledge of various physical phenomena, not just memorized facts. Professionally developed high-quality transparencies were developed for a variety of subjects and used in classrooms. These ranged from maps for teaching geography to many of the sciences including anatomy. When this author published the medical physics textbook, *The Physical Principles of Diagnostic Radiology* in 1977 The images were also provided on transparencies for classroom display with overhead projectors.

The *highly transparent* images could be projected as large bright images on screens with the conventional overhead projectors that had been developed. However, there was a need among physicians, especially radiologists to display radiographic images on screens for classes and conferences. There were two challenges. Photographing the films and mounting in glass slides (for the Magic Lantern projector) required considerable effort and was expensive. Also, the radiographs were much to dark and dense (not highly transparent) to be shown with conventional overhead projectors. Projectors with high-intensity lights, large lens, etc. were developed and used for that purpose.

These were often in the classrooms used by medical physicists within radiology departments but not a significant benefit for teaching physics. One use was showing radiographs that demonstrated imaging physics effects, artifacts, detail, noise, etc. This was valuable in connecting physics to actual clinical images, especially when teaching physics for radiology residents.

13. **Clinical Image Teaching Files**

Before continuing with the image projection methods, we will explore a related topic, the development and use of *clinical images* in teaching medical physics. The image is the primary physical object being learned about in the field of diagnostic radiology and especially for radiology residents in their physics courses. It is the image that is the important connection between the principles of physics and clinical medicine. Effective physics teaching requires the use of clinical images to illustrate many of the image characteristics and factors associated with the physics of the imaging process. This is especially significant when teaching physicians, radiology residents who need to understand the relationship of physics to clinical medicine, not only to make it interesting but also how to apply the knowledge to obtain, analyze, and optimize images to obtain maximum clinical information. This is emphasized by the author who begins physics courses with an image as illustrated in Figure 22.

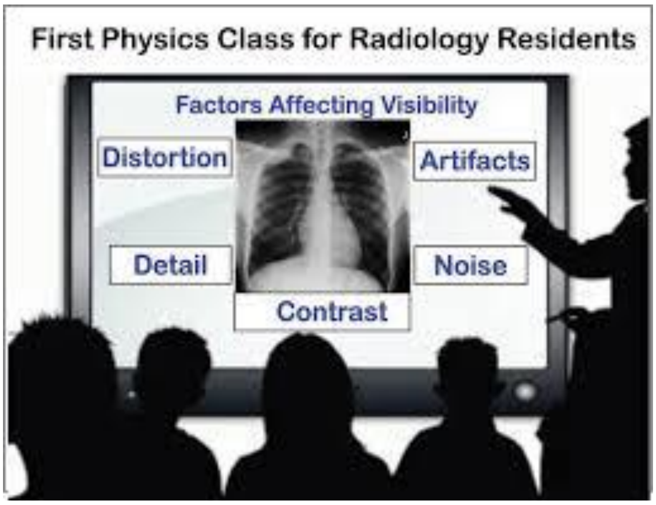


Figure 22. Using clinical images to illustrate physics concepts and applications.

The value of clinical images in teaching medical physics has long been recognized but limited by the availability of images that illustrate the many different conditions that can exist, effects of different levels of visual noise for example. Up into the 1960s medical images, primarily radiographs, were produced and viewed on large films and not practically copied for distribution among educational programs. Each program, and often each teacher, had their collection of images on film that was used for teaching. These were the *teaching files* that were the foundation of radiology education. It was possible for radiologists to collect images of the many different clinical conditions, diseases, etc. that they viewed and develop extensive teaching files. Physicists did not have that opportunity.

At that time in history images available to medical physicists for teaching were of non-human objects, phantoms, test objects, etc. that they had produced themselves. It was to be years later with advances in technology, both photography and digital, that more images of the human body demonstrating physics was to become available to medical physics educators around the world as will be described later.

14. Photography and Slide Projection

The science and technology of photography has developed and evolved over the years with many advances but with minimal contribution to physics teaching until the development and application of transparent images and projection methods in the 1960s. Before then projection of images on transparent film was used extensively for movies or cinema and was well established. It was the development of images on 35mm transparent film and mounted as individual “slides” that was the great breakthrough along with projectors that could be loaded with multiple slides as illustrated in Figure 23.

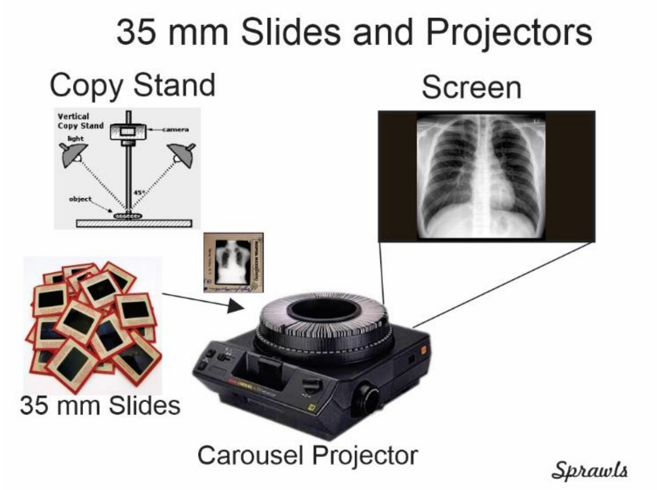


Figure 23. 35 mm slides and projected images for teaching.

As discussed earlier, transparent images mounted in glass slides and the "Lantern" projectors were used in teaching and conferences for years, especially within the medical profession. A limitation was the effort required to produce the photographic transparent images and mount between two glass plates…often requiring a professional photographer. For showing, the slides were individually inserted into a projector and changed manually by a projector operator. These limitations were overcome along with additional advantages with the development of 35mm transparent images and projectors with capacity for multiple slides and remote operation.

The 35mm size film format became the almost universal standard for photography generally in the 1950s…replacing a variety of film formats, 120, 828, etc. The transition to the 35mm format brought many advantages, including a common size for cameras, film, and processing. It was widely used for conventional black and white photography with negatives that were projected with an enlarger in a darkroom and printed as positives on paper.

The radiology profession transitioned to 35mm slides when Kodak Rapid Process Copy Film, and some similar films became available. This was a film with high detail and produced a positive image, not a negative as most films of that time did. Radiographs were photographed on illuminated view boxes and processed in the darkroom used for processing the clinical x-ray images. The process could be used to make slides of printed materials, diagrams, tables, etc. and enhanced the use of 35mm slides by medical physicists, especially in conferences.

Several manufacturers, especially Kodak, Agfa, and Fuji developed 35mm color transparency film that required processing by commercial facilities. It was the Kodak Ektachrome film with its unique emulsion and two-hour processing that became the predominate method for producing slides in many institutions and used extensively by the author for many years.

It was the availability of 35mm color transparent slide photography and projectors including the Kodak Carousel projector that enabled the next era of physics classroom teaching and conference presentations…and provided many new "windows" through which to view and study the physical universe.

This relatively easy to use method for making slides was established in medical physics programs with "copy stands" to mount cameras to photograph diagrams and many other visual representations for classroom presentations. For the first time, it was possible to photograph equipment, procedures, and other aspects of the physical universe and bring into the classroom for viewing and learning.

Another value was slides could be duplicated and shared among teachers and institutions, increasing the efficiency of the educational process. 35mm slides with their many advantages began supplementing or replacing overhead projectors in physics classrooms and conferences in the 1960s.

With the relative ease of producing 35mm images for display in classrooms and conferences using dual projectors and screens became a common practice as illustrated in Figure 24.

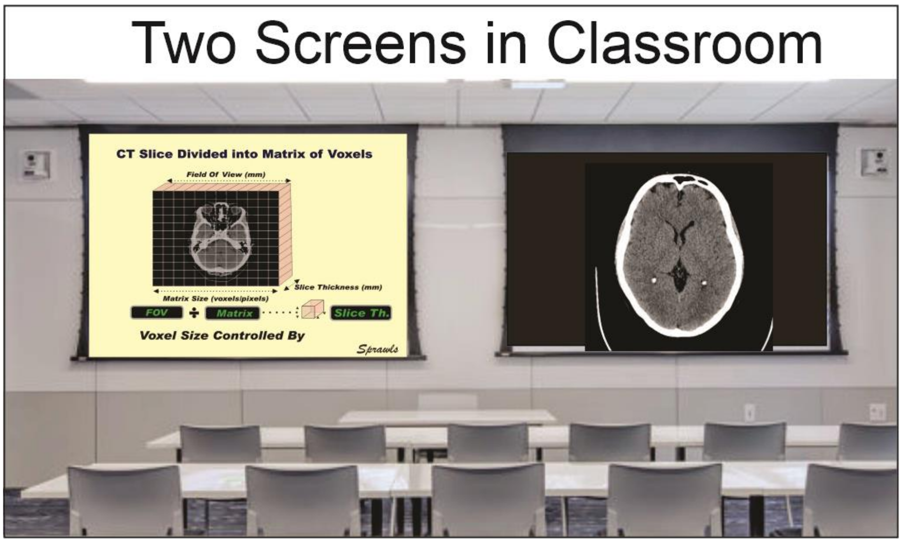


Figure 24. Dual display of images for teaching and conferences.

The display of two side-by-side images enhanced the teaching and learning process in several ways. It was used to compare images to see and understand differences and similarities of objects or conditions…for example normal and abnormal. Another application was to use one screen to display data and the other to show examples of the various conditions.

In review, the addition of projected images, first with overhead projectors and then 35mm slides to the classroom and conferences was the major evolution that provided "windows" and brought the physical universe into the room to be explored and studied under the guidance of experienced medical physics teachers.

15. And Then Came Digital

The research, development, and applications of digital electronics and technology provides the foundation of a new era with many innovations and advances in virtually all areas of society including communications, entertainment, business, healthcare, education, and much more. Our interest here is *physics classroom teaching and learning* and how it is impacted by the digital revolution.

Up until now we have followed the evolution of the physics classroom with respect to factors that contribute to the effectiveness and efficiency of the teaching and learning process with a special emphasis on "windows" to bring the physics universe into the classroom where teachers can lead learning activities that result in more effective and useful knowledge for the students. We have observed that this evolution has been based on developments in technology ranging from the various writing and drawing boards to image projection methods, especially the overhead projectors and concluding with 35mm slides and projectors. This was followed by the digital technology applications and a major revolution in physics classroom activities.

Digitized Images

A major factor was the transition from analog images recorded on film, both clinical radiographs and general photography 35mm slides to digitized images. Because of the large market throughout society for digital photography developments were ongoing and educators benefited from that. The advantages of digitized images for classroom activities include easier to produce and less expensive than 35mm slides and much more efficient to organize, store, and transmit to various locations as needed. With ongoing developments in digital computer technology and software there were several methods for producing images specific for physics classroom teaching as discussed later.

Software for Organizing and Presenting Images

As the technology (cameras, scanners, projectors, etc.) was developed to produce images for classrooms software was also developed for producing text, organizing images, and managing the classroom presentations. *PowerPoint* developed by Microsoft became the standard.

Digital Image Projectors

The technology that had to be developed to enable the display of digital images in classrooms were projectors. The early classroom projectors for digital images were video projectors based on the principle of cathode ray tube (CRT) video displays that was the standard at that time before the development of light emitting diode (LED) displays and projectors. Figure 25 shows the use of a projector for computer generated digital images for teaching medical physics.

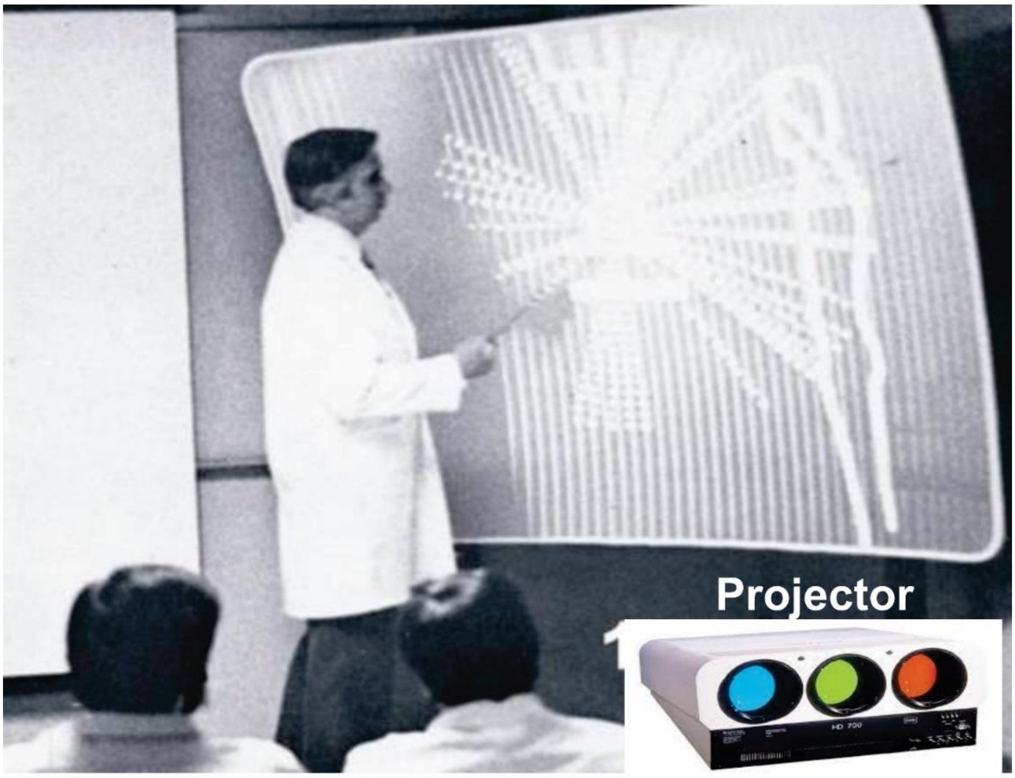


Figure 25. The author using a projector for digital images in the 1980s. A picture of the projector is shown on the lower right corner.

These early projectors used three primary colors as separate but overlayed images to produce the image seen on the screen. The image was formed as a scanned raster of lines. The video scanning standard at that time was 525 lines of which approximately 485 lines were in the image itself. This could not provide the image detail as good as 35mm slides.

It was the development of LED and other solid-state image displays and projectors with the 1080p standard (1920×1080 pixels) that provided adequate image detail for classroom and conference presentations, including medical images.

As the digital technology developed to provide adequate image quality and was generally available the transition from 35mm slides began. In 1999 the AAPM Annual Meeting provided for BOTH 35mm slides and digital PowerPoint presentations. In 2002, it was only digital PowerPoint.

16. Digital Images for Teaching

As digital projectors became available in classrooms and conferences the effort was to develop images in the digital form. This occurred in several ways and was a major contribution to the development of the modern digital era of classroom teaching.

Scanning 35mm Slides

Many educators had extensive collections of slides they had created for teaching. A decision was either to continue teaching with slides or transition to digital for the several advantages it provided. Slides could be converted with either digital scanners or cameras but required considerable time and effort. This had value for special, difficult to replace images, especially clinical teaching files. However, many educators used this opportunity to develop new high quality digital teaching images and visuals with the several methods that were becoming available.

Digital Cameras and Photography

Replacing the 35mm cameras with digital cameras provided several advantages, especially no costly and time-consuming processing. Images were available instantaneously. This continued the photographing of equipment and procedures, copying printed materials, and clinical images as was dome with the film cameras.

Digital Computer Generated and Processed Images

Up until the development of significant digital computer graphic capability, generally in the 1980s all visuals, diagrams, etc. for classroom display were drawn by hand on classroom boards or on paper and copied or photographed for showing with overhead projectors or 35mm slides. In addition to requiring considerable effort the quality of the illustrations was limited.

A major development that expanded the scope of images and visuals to be used for classroom "windows" was the availability of computer graphics and image processing software that physics teachers can use to create visuals. The software programs use two different mathematical methods for representing images, each with distinct characteristics, advantages, and applications.

The software generally designated as "Draw" programs represent the characteristics of each object (size, shape, position, color, etc.) in the image with a combination of numerical values, a mathematical vector. The great advantage is these can be adjusted during the process of drawing illustrations. An example of a classroom visual created with this type of software is shown in Figure 26.

The transition from hand-drawn to computer generated and processed visuals for physics classrooms and conferences contributed to more effective and efficient teaching and learning activities.

When these digital images were inserted into presentation software, typically PowerPoint, 35mm slides and carousel projectors generally faded into history.

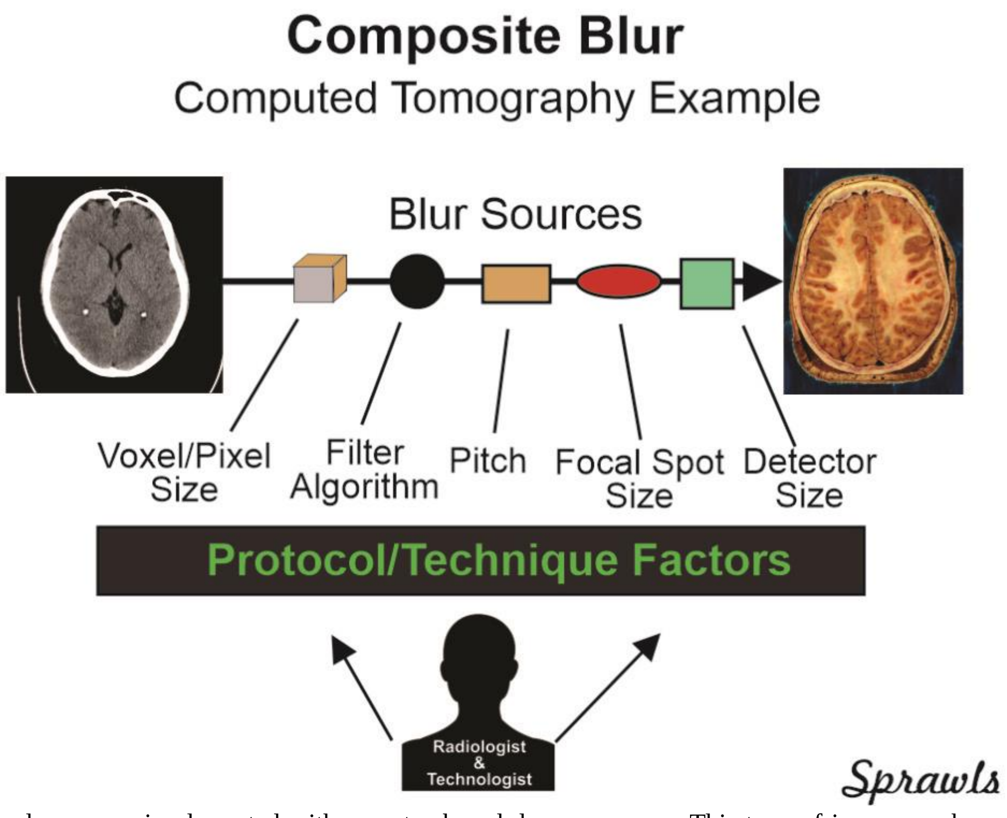


Figure 26. A classroom visual created with a vector-based draw program. This type of image can be used by medical physics teachers to illustrate and explain many factors associated with the formation of CT images.

Software generally designated as "Paint" programs represent each image as a matrix of pixels, like how clinical medical images are formed. These programs provide a variety of image processing functions that can be used to illustrate different image characteristics and conditions. An example is illustrating different levels of image detail and noise as shown in Figure 27.

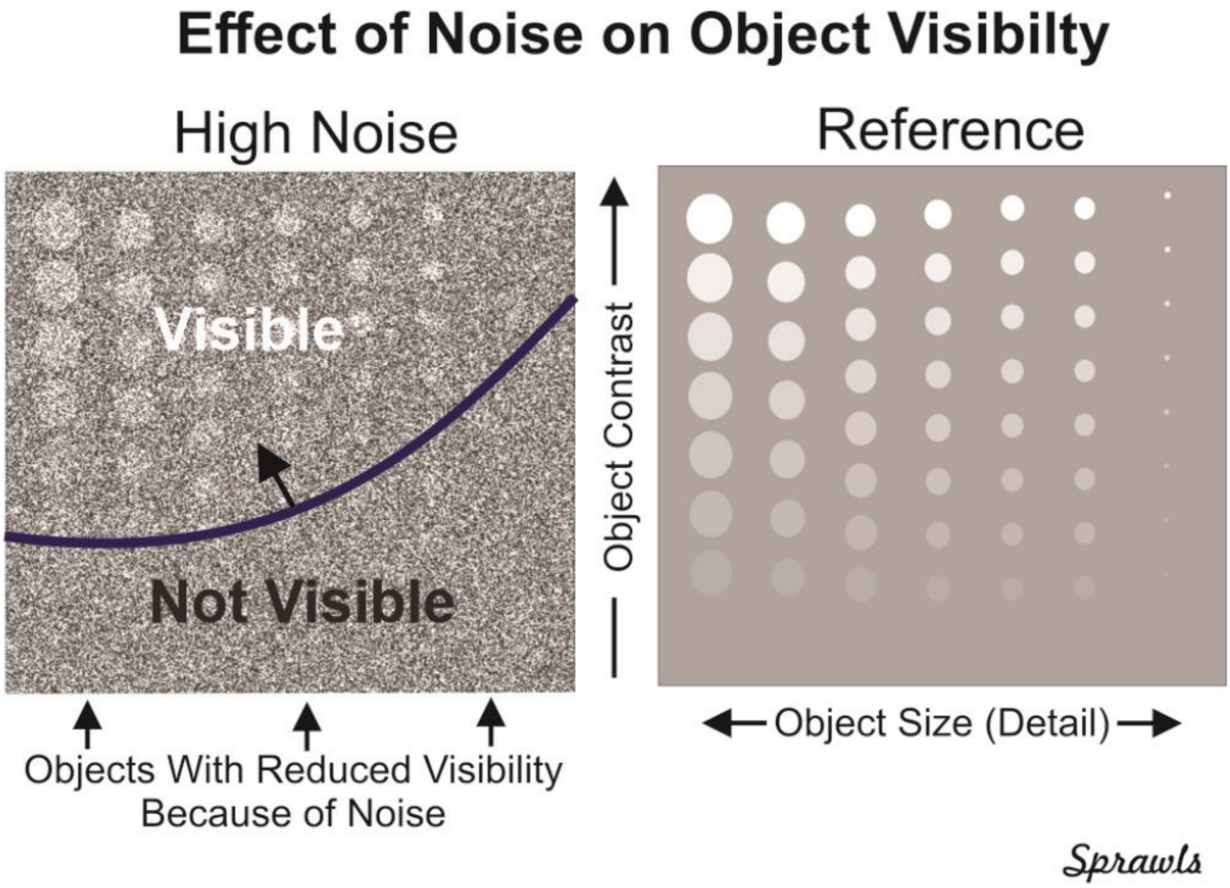


Figure 27. Illustrating image characteristics by processing an limage (Reference) with a pixel-based Paint program
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By using the two types of programs, DRAW and PAINT, a variety of clinical images can be created and then inserted into illustrations developed with DRAW programs. This is illustrated in Figures 26 and 27.

Computer Simulations of Physics Phenomena

Many physics phenomena, events, interactions, etc. can be described with mathematical relationships or equations. Computer programs based on these relationships can produce *virtual simulations* of actual physical events. At one time in history analog computers were used, especially for phenomena like radioactive decay, attenuation of radiation, etc. With digital computers becoming more widely available and with software with the capability, computer simulations became a valuable method for physics education. A major application is in physics laboratories where many physical phenomena, especially relating to large equipment like nuclear reactors, MRI systems, can be simulated and experiments and observations conducted by students.

In the classroom computer simulations can be used by teachers to provide a dynamic and interactive view of physics events within their discussions. In 1981 this was demonstrated by the Author in an exhibit (received Cum Laude award) at the RSNA Conference shown in Figure 28.

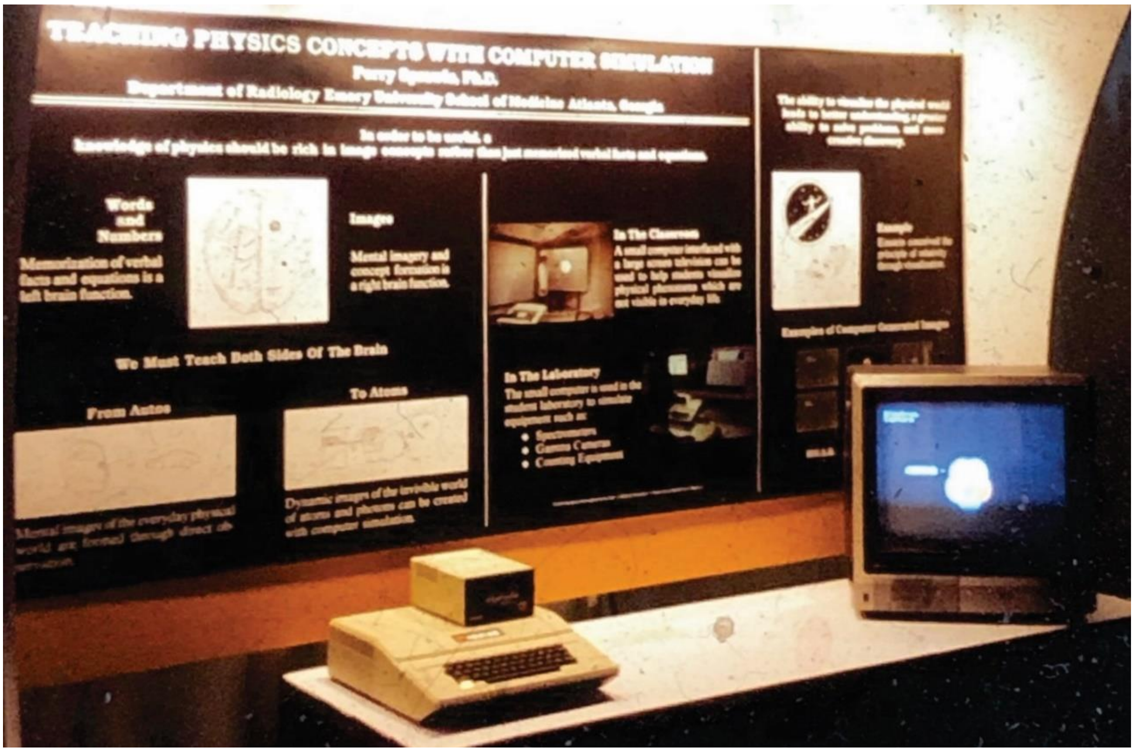

Figure 28. An exhibit at the RSNA 1981 Conference demonstrating the use of computer simulation for teaching medical physics.

The excellent IT skills of many medical physicists led to the development of a number of computer simulations. However these are difficult to develop. Most importantly - they are software dependent and usually have short life cycle (some of the simulations stopped working after several years). Some of these simulations were commercialized what prolonged their life, but still the use of specific software makes their practical implementation more difficult (especially in developing countries). This trend lost speed during the second decade of the 2000, as a number of simulations stopped working with the introduction of new 64-bit PC Operating systems, which discouraged some teams.

Very useful teaching resources are interactive GIF images. Although not a simulation, these provide an easy way to understand complex processes. An example of such resources is the collection of the Colorado University.

In order to support the spread of information about various short-lived e-learning materials and simulations IOMP opened in 2012 a new online Journal (Medical Physics International). This free e-Journals (www.mpijournal.org) is oriented toward education/training and professional issues, including e-Learning, and has thousands of readers per month.

17. Networks and Sharing Images

The transition from analog images on transparences and 35mm slides to digital images was the foundation for the next major advancement in classroom teaching and learning.

The classroom window was now opened to view images created and shared from anywhere in the world.

This gave physics teachers access to an extensive collection of images and visuals that were on various websites around the world. Of special value to medical physics teachers are clinical images, images by equipment manufacturers, and by medical physicists and educational institutions. While most are not posted specifically for classroom use, they can be used following established academic and intellectual property guidelines.

For an example of what can be found us Google Image search, https://images.google.com/ and enter the term “x-ray tubes”. Some organizations provide images on the web specifically to be shared and used by others in medical physics educational activities. These include the *Sprawls Resources* at http://www.sprawls.org/resources/ and the free online Medical Physics Encyclopedia at http://www.emitel2.eu/emitwwwsql/encyclopedia.aspx .

18. Teleteaching

The development of the internet and images in a digital format made it possible for a physicist to teach classes located almost anywhere in the world. At first, there was no specific software for this, that was to come later, but the Author combined several technologies including a website for images and Skype for voice to teach a remotely located class and designated this as *Teleteaching* as illustrated in Figure 29.

Figure 29. The Author teleteaching a class in Malaysia.

Teleteaching with this method provided the values of conventional classrooms with personal interactions with the additional advantage of having teachers located in other institutions.

19. The Virtual Classroom and Online Learning

The major, and perhaps dramatic, change to result from developments in technology was the transition from physical to virtual classrooms, with students and teachers physically separated from each other. This brought some advantages, especially in terms of efficiency relating to travel to class and students could "attend" from almost anywhere in the world. Significant disadvantages are the loss of direct physical interactions and the perception and appreciation of a classroom as a "space for learning".

The virtual classroom and online learning essentially "saved" educational programs in the early 2020s when the COVID epidemic prevented physical classroom gatherings.

20. The EMERALD Project

The concept for sharing educational digital images was first developed in 1995 by the international (EU) project EMERALD (acronym of: European Medical Radiation Learning Development). The project developed structured medical physics training timetables and associated with these original Educational Image Databases (IDB). These were one of the first ever IDB on CD-ROM with ISBN number as paper books, thus forming one of the first e-books in the world.

The project EMERALD was followed by the similar international (EU) project EMIT (European Medical Imaging Technology Training) which further develop such e-learning materials. Both projects developed original e-learning materials (supported with over 3000 digital images) in the fields of: X-ray Diagnostic Radiology, Nuclear Medicine, Radiotherapy, Magnetic Resonance and Ultrasound Imaging. In 2004 the projects received the inaugural EU Award for education – "Leonardo Da Vinci" award. Over 5000 of these CDs were distributed to medical physicists globally, these being specially effective for development of medical physics education in Low and Middle Income countries. These can be accessed free at: http://www.emerald2.eu/cd/Emerald2/

Figure 30. EMERALD and EMIT CD-ROMs

The existing digital images and materials allowed to add these on a specially built educational websites. The first two such websites (opened in 1999 and still in use) are www.emerald2.eu and http://www.sprawls.org/resources/index.html. The effectiveness and usefulness of these websites is seen by their thousands of users globally. A specific characteristic of these web sites is that their software is own made and with user-friendly interface.

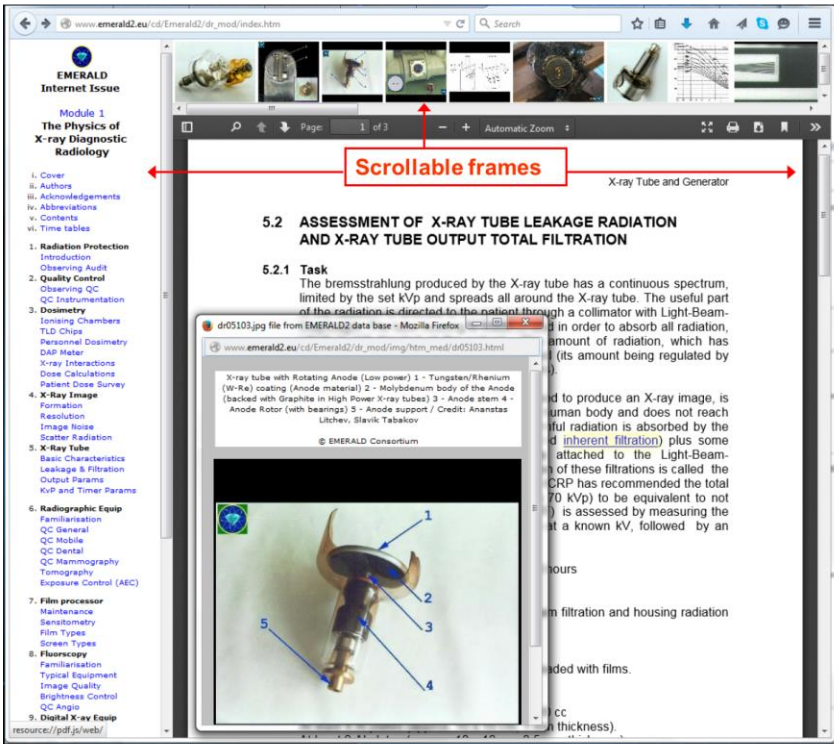

Figure 31. Interface of EMERALD free website

In the period 2002-2012 some of the digital images from both websites were used as background for the preparation of the first on-line e-Encyclopedia of Medical Physics (www.emitel2.eu), part of the international (EU) project EMITEL. This web site was also based on own software and user-friendly interface. The e-Encyclopedia of Medical Physics was supported by the first Scientific Dictionary of Medical Physics Terms (translated to 31 languages by now). Over 150 specialist from 30 countries took part in the development of encyclopedic articles, where additional 200 specialist took part in the development of the Scientific Dictionary.

The e-Encyclopedia was updated in the period 2019-2021 by an Editorial Board, including the author. Alongside the free web site, was published on paper by CRC Press. The Encyclopedia includes nearly 4000 articles and hyperlinks and over 1500 images, diagrams and tables. All materials in the Encyclopedia were made with educational emphasis, thus supporting both students and lecturers in medical physics.

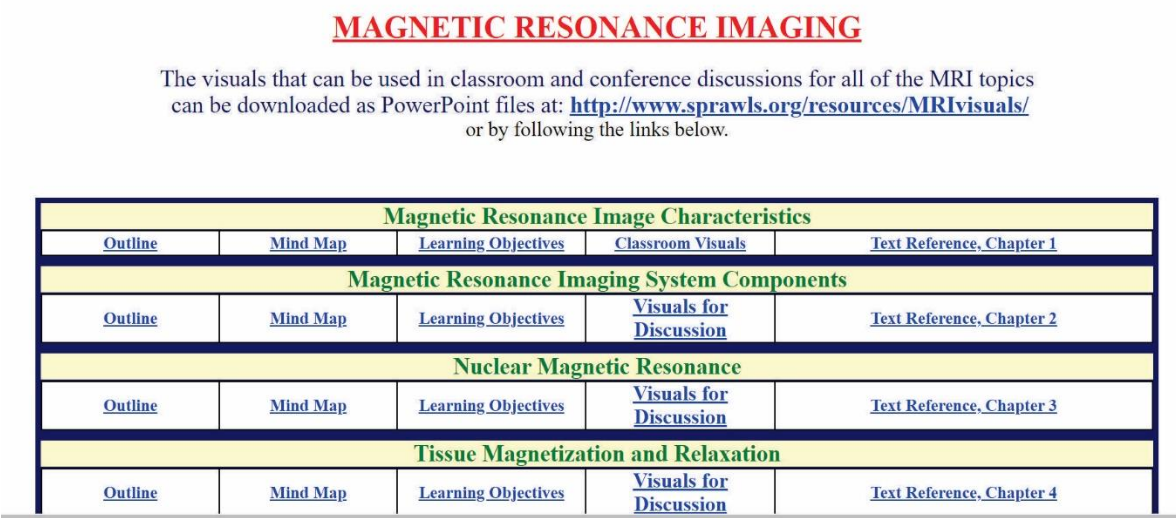

Figure 31. Example Interface of Sprawls Resources free website for enhancing classroom presentations available at www.sprawls.org/resources .

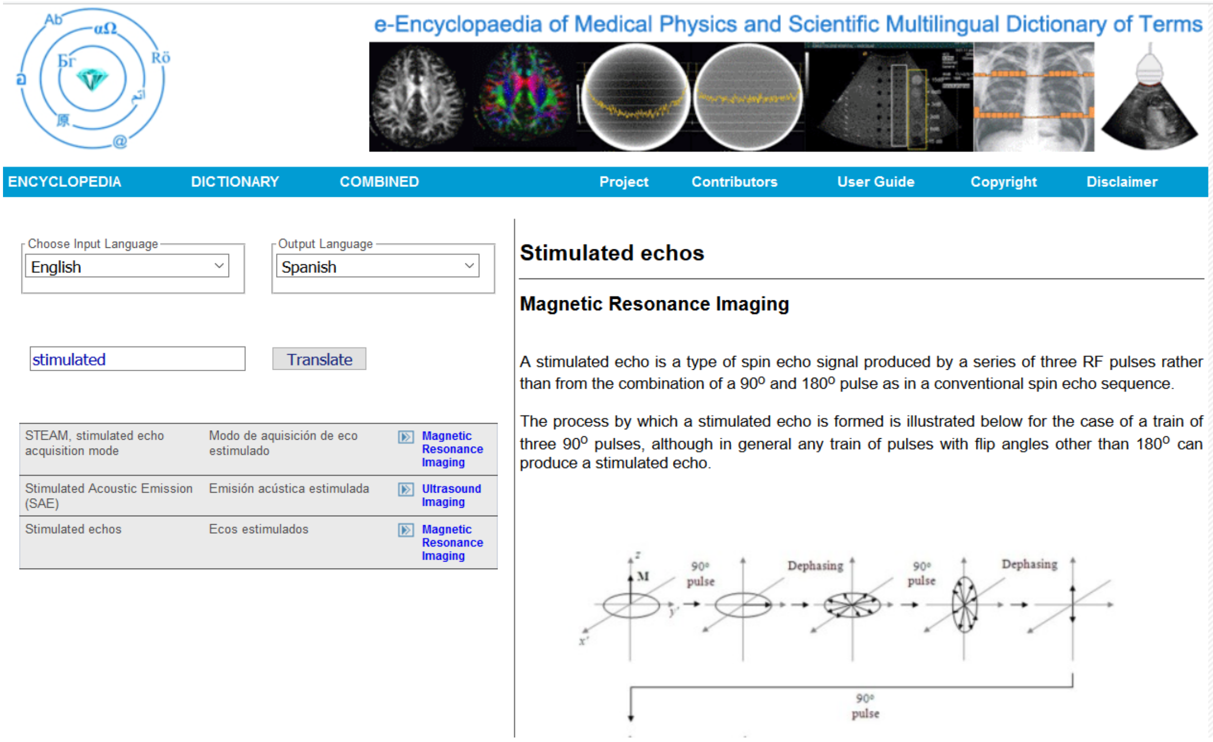

Figure 32. Interface of Encyclopaedia of Medical Physics free website

A very large and effective free web site was developed by the IAEA during the first decade of 2000s. This web site is orientated to Radiation Protection of patients: https://www.iaea.org/resources/rpop Currently this is the most often website in medical physics.

21. Conclusion

Even though the ***Classroom*** has evolved over the years, its purpose of bringing students and teachers together for *effective* and *efficient* learning and teaching continues. Many factors have contributed to the enhanced value of the classroom, the major one being the developments in technology, especially digital.

Figure 33 illustrates this by comparing the Authors classrooms over a 60-year period.

Figure 33. The developments and evolution in the Author's physics classroom over a period of 60 years.

The "technology" available in the first classroom in 1960 was a blackboard and some pieces of chalk. This was the only "window" for connecting students to the physical universe and dramatically limited their ability to develop effective knowledge structures beyond symbolic representations consisting of words and mathematical symbols. Much of the student's attention was devoted to reproducing what was written on the blackboard as notes for future study. In general, delaying the learning process to later and not occurring in the classroom.

A major objective of the education provided was high scores on test and examinations, not knowledge that could be applied in future "real world" activities.

Now the classroom 60 years later used by the Author in the College on Medical Physics at the ICTP. A major value to the students is the in-person interaction both with the teacher and with other students. The classroom has "windows" in the form of images and visuals that enables the students to see and interact with the physical universe, providing the ability to develop high-effective knowledge structures that will support many medical physics activities.

Everything presented and discussed in the classroom, especially the images, are provided on-line to the students for future study and refreshing what they learn in class.

A concluding perspective from the Author

The extensive developments in technology over the years along with research and innovations in the learning and teaching process have provided major enhancements to the classroom as a highly effective "space for learning".

The technology is the "tool" and the physicists are the teachers.

22.The Author

Perry Sprawls, Ph.D. is a clinical medical physicist and educator in medical imaging physics and clinical applications. He became a Distinguished Emeritus Professor of Radiology at Emory University in Atlanta concluding a 45-year career advancing the practice of radiology and medical imaging with an emphasis on the education of physicians, physicists, and other imaging professionals. This was achieved by authoring several books, developing and conducting continuing educational programs and courses and providing high-quality visuals to enhance classroom presentations by medical physicists are designated as the *Sprawls Resources* and are provided without cost for all to use by the Sprawls Educational Foundation online at www.sprawls.org. With over 30 years as a Co-Director and Faculty of the College on Medical Physics at the International Centre for Theoretical Physics in Trieste, Italy he has provided classes for 100s of medical physicists from over 35 of the Developing Countries of the World. In addition to the classes the physicists are provided with additional educational materials including the Sprawls Resources to develop and enhance medical physics programs in their countries. In his ten-year service as founding Co-Editor in Chief of the *Medical Physics International* journal a major effort has been providing publications to advance medical physics education around the world.


Dr. Perry Sprawls

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A BRIEF HISTORY OF FRACTIONATION IN EXTERNAL-BEAM RADIOTHERAPY

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Contents

1. Introduction

Throughout the history of external beam radiotherapy, the practice of fractionation of treatments has gone through many phases, ranging from extreme hyperfractionation with about 100 fractions to extreme hypofractionation with just a single fraction. In this paper we will review how and why we have experienced these widely different practices and what we can expect in the future.

2. Early Experiences

Within a few months after Roentgen's discovery in 1895, x rays began to be used, rightly or wrongly, to treat a wide variety of medical ailments such as eczema, acne, varicose veins, leprosy, tuberculosis, keloids, neuralgia, migraine, epilepsy, hirsutism, and cancer. The most important, of course, has been the treatment of cancer. Although there is considerable controversy as to when the first cancer treatments began, it is claimed that the first attempt at this was on January 29, 1896, when Emile Grubbé, a medical student in Chicago, who had established a small business making x-ray tubes, initiated a course of treatment on a Mrs. Rose Lee, who had a breast cancer. He delivered a series of 18 one-hour treatments with the breast in contact with the x-ray tube. Treatments were terminated after the patient developed painful skin burning. It is not clear if the treatments provided any local control, however, since the patient died of systemic disease within one month. There is some considerable dispute as to whether this was the *first* application of x rays to treat cancer, however, since Grubbé did not document his claim until 1933(1). In contrast, Victor Depeignes, from Lyon, France did, immediately, document his treatment of a stomach cancer patient (his neighbor!) starting on July 4, 1896(2). He delivered 80 sessions of 15-30 minutes at two sessions per day and reported a reduction in pain and tumor size, but the patient died before the planned course of treatment could be completed. The first documented *successful* cancer treatment was for a patient treated by Tor Stenbeck, in Sweden, for a basal-cell carcinoma (see fig. 1), using a total of 99 fractions!(3).

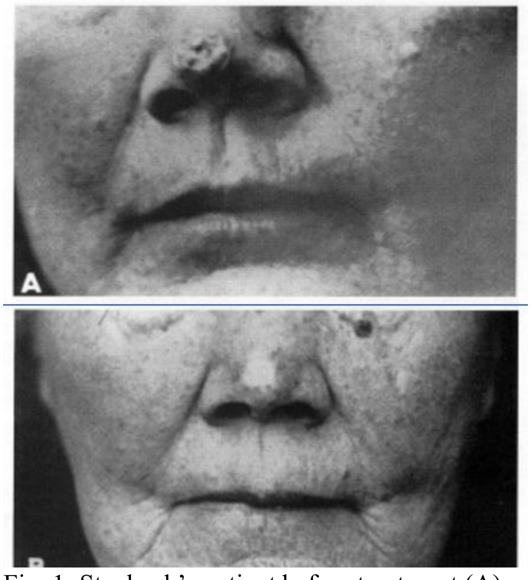

Fig. 1: Stenbeck's patient before treatment (A) and on follow up 30 years later (B).

Such extreme hyperfractionation was common in these early days of radiotherapy, not because it was believed that, *radiobiologically*, such fractionation was necessary, but because of *physical* constraints at the time. Firstly, the output from early x-ray units was very low, and treatment sessions lasting many days would likely have been necessary to deliver enough dose to control the cancers. Secondly, it was because outputs of these primitive x-ray machines varied considerably from use to use, so exposures were highly unpredictable. It was only after completion of each treatment session that the "dose" delivered could be determined using, for example, the blackening of photographic paper strips placed on the skin of the patient to determine the exposure (see fig. 2).

Record of X Ray Exposures.

Date	Hardness of Tube	Exposure Min	Exposure Sec.	Amp.	M'a.	Filter	Areas.	Paper and Value on Scale	Remarks
	Bauer Qualimeter								
9.3.14	7½	10		5	3½	3mm	1	10+	
	8½	10		5	2	"	2	10+	
12.3 14	9	15		4	1½	2	3	No paper	
12 3 14	"	"		"	"	2	4	No paper.	
18.3.14	8	"		5	3	2	1	10	
"	9	"		4	1	2	2	8	
25.3.14	9	15		5	2½	3	5	5	
"	9	15		5	2	3	6	4	
30. 3. 14	9	15		5	2	3	3	4	
"	9	15		5	3	3	4	4	
6. 4. 14	9	"		4	2	"	1 back.	5	
"	9	"		2	1½	"	2 back.	4	Brush not working well.
15. 4. 14	7-8	10		4-4½	2-2½	"	1	5	
	7	10		4½	2½	"	2	5	
	9	15		5	2	Dev. strong.	5	2	Improving.
				6	3	"	6	2	
6.5.14	9	15		5	2½	3mm.	5	6	
	6½	20		4½	2	"	6	6	
19.5.14	9	15		6	3½		3	8	
"	"	"		"	"		4	8	

Fig. 2. Typical treatment record of an early course of radiotherapy, showing that the exposure (as determined by the blackening of photographic paper strips) varied considerably from day-to-day.

It was not until 1914, with the development of the hot-cathode X-ray tube by William D. Coolidge, that high, predictable, exposures became possible. There followed several years of uncertainty regarding the best fractionation to use.

There were essentially two schools of thought about fractionation: the single-fraction, *Erlangen School*, headed by Hermann Wintz,(4), which believed that only with single fractions could you cure a cancer, and the multiple-fraction, *Paris School*, headed by Henri Coutard, which believed that only by fractionation could you cure cancers without exceeding normal tissue tolerance. According to the single-fraction school, fractionated treatments were inferior because they allowed cancer cells to proliferate during the course of treatment and, to overcome this, would have required doses to be delivered that were so high they would exceed the tolerance of surrounding normal tissues. They considered fractionated radiotherapy to be the "*primitive method*" and "*weak irradiation.*" The multi-fraction school, on the other hand, based their belief on the 1919 radiobiological experiments of Claude Regaud, in France, published in 1922 (5). He found that a ram could be sterilized by irradiation of its testes without exceeding the tolerance of the skin of the scrotum, only if the treatments were fractionated. They argued that the testes could be considered a good model of a proliferating tumor and that the skin represented normal tissues. Hence, only with fractionation could high enough doses be delivered to cure cancers without exceeding normal tissue tolerance. This controversy continued until 1932 when the radiotherapy world realized that fractionation was essential after Coutard, at the Institut Curie in Paris, published his excellent results with fractionated therapy (6).

Although Coutard's work demonstrated the importance of fractionation, it did not establish an appropriate fractionation technique, since he and his colleagues had used a wide variety of fractionation schedules. With regard to fractionation, the overall duration of their courses of therapy and the number of fractions was varied dependent upon the size of the tumor and ranged from as short as one week to as long as six or seven weeks, with appropriate dose/fraction, always treating seven days/week and often at two fractions/day. Another important consideration was the dose rate they employed. All the patients were treated at low dose rate, not necessarily because Coutard and his colleagues believed that this would be superior to high dose rate, but because the relatively primitive equipment at that time available to them at the Institut Curie could only be operated at low dose rate. Treatment sessions typically lasted 30-60 minutes. It was not until François Baclesse took over from Coutard as head of the Institut Curie in 1937 using more modern equipment that a standard fractionation method was established of about 30 high dose rate fractions of about 2 Gy delivered over about six weeks, often referred to as the "*Paris*" technique (7). Many radiation oncologists visited the Institut Curie to learn from their expertise and this fractionation schedule became the standard of treatment in many countries for the next 50 years or more. One of the students of Baclesse was Gilbert Fletcher who, in 1948, introduced such a treatment regime when he was appointed to the M. D. Anderson Cancer Center in the USA, where it remained the most common fractionation for the next 60 years-or-so (7). We now know that there is a good *radiobiological* reason for the success of such a fractionation scheme, and this relates to the difference in the ability of late-reacting normal tissue cells and tumor cells to repair sublethal damage, as illustrated by the cell-survival curves in fig. 3 (8). This shows that, at low doses (and, therefore, low doses/fraction), the cells of late-reacting normal tissues exhibit a higher survival rate than those of typical cancers but this is reversed at high doses. There is a "window of opportunity" centered around about 2 Gy, where this advantage is most efficiently utilized.

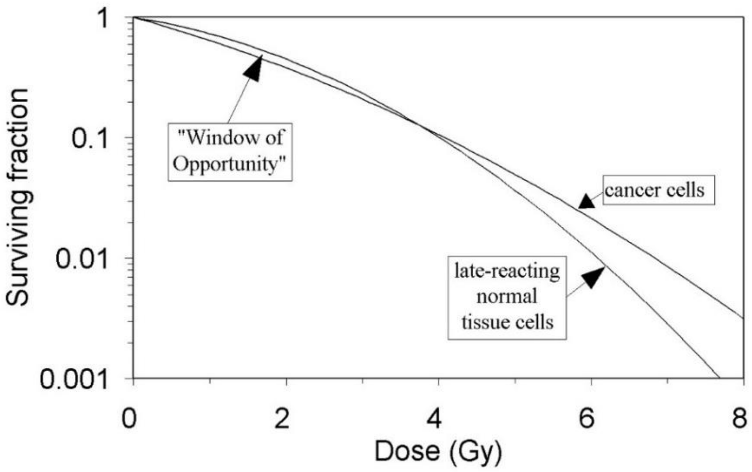

Fig. 3. Surviving fraction as a function of dose for late-reacting normal tissue and cancer cells, illustrating the "window of opportunity" centered about 2 Gy (8).

Just after World War II a somewhat different approach was more common in some countries, however, necessitated by the lack of sufficient treatment machines for each patient to have as many as 30 fractions. Most notable was the Ralston Paterson "*Manchester*" technique developed at the Christie Hospital, in which he delivered daily treatments of about 3-3.5 Gy over 3-4 weeks. After many years it was realized, however, that the *Manchester* technique was causing an unacceptable risk of late complications, and about 2 Gy fractions then became the standard (7). Because of many technical developments, however, this is not necessarily true today. So what has changed?

Almost all of the early clinical experience involved the use of relatively low-energy x rays in the range 80 – 300 kVp. With very poor depth-dose characteristics, this meant that the tumor often received a lower dose that the normal tissues surrounding it, especially the skin. Indeed, radiation therapy was often referred to as the "skin burning" treatment by potential patients and referring doctors. In that respect it did not have a good reputation and was often avoided in preference to much more debilitating surgery. It was not until the advent of skin-sparing Co-60 and linear accelerator radiotherapy in the mid-1950s that it became possible to consistently deliver higher doses to deep-seated tumors than to the intervening normal tissues. Although the vast majority of treatments continued with conventional fractionation at about 2 Gy/fraction, some new fractionation schemes began to emerge for specific applications.

3. Hypofractionataion

3.1. *Treatment of bone metastases*

With the availability of skin-sparing radiotherapy, it became possible to deliver single-field treatments to lesions not too deep below the surface without exceeding skin tolerance. Common among these was the treatment of painful bone metastases. Since these were usually not meant to be curative, just palliative, fractionation schemes were developed with fewer treatments at higher dose/fraction, which were more convenient for patients. Over the years, numerous clinical trials were developed to study various fractionation schemes such as 10 fractions of 3 Gy, five fractions of 4 Gy, four fractions of 5 Gy, and even one fraction of 8 Gy. Indeed, an international survey published in 2009 found over 100 different hypofractionation schemes that had been used to treat bone metastases (9).

Such hypofractionation schemes were not confined to palliative therapy, however. By using stereotactic techniques radiation, with beams directed from multiple directions with the patient immobilized in order to minimize the dose to normal tissues and make the effective dose (e.g. the Equivalent Uniform Dose) (10) less for normal tissues than for tumors, it became possible to deliver treatments at high dose/fraction without exceeding tolerance. This is illustrated *radiobiologically* in fig. 4, which shows that the window of opportunity widens considerably due to the physical geometrical sparing of normal tissues inherent with stereotactic radiotherapy and represented here as the geometrical sparing factor, *f*, where:

$$f = \frac{effective\ dose\ to\ normal\ tissues}{effective\ dose\ to\ tumor}$$

Note that it was assumed in fig. 3 that the effective dose to normal tissues was the same as that for the tumor. This was a reasonable assumption in the early days of megavoltage radiotherapy but, with the advent of highly conformal techniques such as stereotactic radiosurgery and stereotactic body radiation therapy (SBRT), it became possible to keep the effective dose to normal tissues less than that to tumors. As shown in fig. 4, even a modest geometrical sparing factor of just 0.8 widens the window of opportunity to over 10 Gy, making hypofractionation possible.

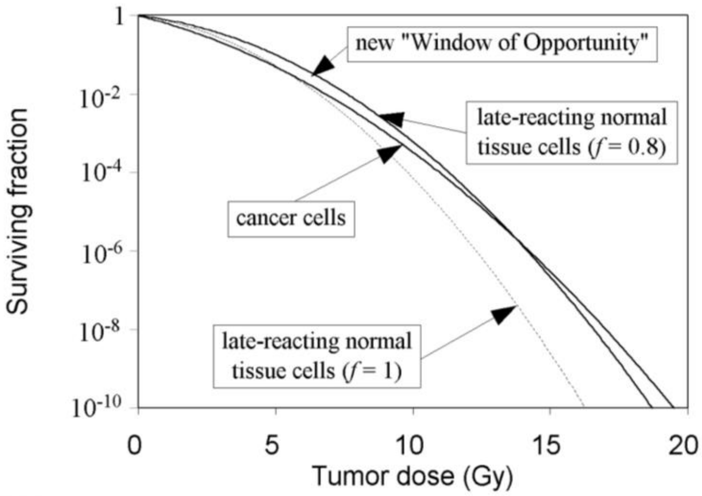

Fig. 4. Surviving fraction as a function of tumor dose for cancer cells and those late-reacting normal tissues, assuming a geometrical sparing factor of 0.8, illustrating that the “window of opportunity” widens to include doses over 10 Gy.

3.2 *Stereotactic radiosurgery*

In 1951, the Swedish neurosurgeon Lars Leksell introduced the concept of using single, very high doses of radiation employing multiple small beams directed at the lesion from multiple directions using stereotactic frame technology, for the treatment of small brain abnormalities, a technique now referred to as stereotactic radiosurgery (11). This led to his development of the gamma knife in the 1960s with which about 200 Co-60 sources, each with its own collimator, produced beams aimed at the lesion from different directions. Single doses as high as about 24 Gy (for very small lesions) were delivered. Due to the success of gamma knife radiosurgery, existing linear accelerators began to be modified to mimic the gamma knife treatments in the 1980s (12) and hypofractionation schemes began to be investigated ranging from 10 fractions of 4 Gy to 3 fractions of 12 Gy (13). The success of intracranial hypofractionated stereotactic radiosurgery with linear accelerators led to the development of hypofractionated stereotactic radiotherapy to other body sites.

3.3. *Stereotactic body radiation therapy*

The 1990s saw the development of stereotactic body frames which, along with advanced imaging and treatment planning technologies, made it possible to deliver high doses at high dose/fraction to extracranial targets without exceeding normal tissue tolerance known as Stereotactic Body Radiation Therapy (14). Since then, doses/fraction from about 6 – 30 Gy in 1 – 5 fractions have become standard practice for the treatment of many cancers, with dozens of clinical trials and hundreds of publications describing SBRT techniques and clinical results. In addition to the convenience and cost-saving aspects of such hypofractionation, there is a potential radiobiological benefit for cancers that contain cells that exhibit a high ability to repair sublethal damage i.e. have a low α/β ratio. Two such examples are prostate and breast cancers. For other cancers, typically exhibiting a high α/β, however, more fractions rather than fewer should be radiobiologically superior, and this was the basis for numerous clinical trials of hyperfractionation.

4. Hyperfractionation

Hyperfractionated radiotherapy refers to the use of more than the typical 30 fractions used in conventional fractionation. This means use of doses/fraction considerably lower than 2.0 Gy. One problem with simply reducing the dose/fraction, is that the course of therapy lasts considerably longer than the normal 5 – 7 weeks, thus allowing cancer cells to repopulate during the course of therapy. This may work for very slow growing cancers but would be disadvantageous for others. This has usually been avoided by the use of 2 – 3 fractions per day. Typical doses/fraction for these studies ranged from 1 – 1.6 Gy. The outcome of numerous clinical trials of hyperfractionation in the 1970 – 2000 period has been that there is no consistent demonstration of any benefit relative to conventional fractionation (15). Since treatment of patients several times each day is both inconvenient and costly, it is not surprising that such treatment regimens are rarely used today.

5. Accelerated Fractionation

An approach for the treatment of rapidly growing cancers, is to use the dose/fraction of conventional fractionation (about 1.8 – 2.0 Gy) but to treat at two fractions/day to approximately the same total dose (7). Unfortunately, this has generally run into the problem of excessive acute reactions, which has led to having to give the patient a 2 – 3 week rest half way through the course of treatment, thus negating the advantage of giving the cancer cells less time to repopulate. The result is that such two fractions/day accelerated fractionation has never gained wide acceptance and is rarely used today (16).

6. Accelerated Hyperfractionation and Split-course Radiotherapy

In an attempt to take advantage of the radiobiological benefits of both hyperfractionation and accelerated fractionation, Wang developed accelerated hypofractionation consisting of 1.6 Gy per fraction, two fractions per day with a minimum of four hours between fractions, for 12 days, 5 days a week for the treatment of cancers in the oropharynx and supraglottis. After the first 24 fractions the patients were given a two-week rest to allow acute reactions to subside (17). Often referred to as split-course hyperfractionated radiotherapy, the insertion of a two-week rest part way through treatment allowed the cancer cells to repopulate and, like accelerated radiotherapy, this regimen was never widely adopted.

7. Continuous Hyperfractionated Accelerated Radiation Therapy

A potential way to treat rapidly growing cancers with accelerated hyperfractionation while avoiding the need to have a rest period part way through treatment has been to use relatively high doses/fraction three fractions/day. This was the basis for the Continuous Hyperfractionated Accelerated Radiation Therapy (CHART) trials initiated for the treatment of advanced head and neck and small-cell lung cancers at the Royal Marsden Hospital, London, in the 1990s (18). The fractionation was 1.5 Gy delivered three times/day over 12 successive days to a total dose of 54 Gy. The need to rest the patient part way through treatment was eliminated since the peak in acute reactions did not occur until *after* the course had been completed. With 54 Gy delivered in just 12 days, however, the patients suffered very extensive and painful acute reactions, requiring them to be hospitalized for observation and treatment. With some small modifications, such as weekend less treatments (CHARTWEL), this regimen was the basis of several clinical trials, which tended to show some benefit in terms of tumor control but which never gained wide use probably due to the excessive acute reactions, requiring hospitalization, and the inconvenience of treating patients at three fractions/day.

8. So Where Are We Today?

In the past decade, things have changed considerably due, primarily, to the development and exploitation of many advances in technology. Irradiation of normal tissues surrounding targets can be significantly reduced by employment of stereotactic techniques, image guidance, advanced planning, etc., such that avoidance of complications has become secondary to maximizing the probability of tumor control. No longer do we have to rely on fractionation to avoid late normal tissue complications and long courses of therapy to minimize excessive acute reactions. We can now keep these under control by avoiding the delivery of high doses to surrounding normal tissues. The result is an enormous increase in clinical trials of hypofractionated short courses of radiotherapy. This has the added benefit of reduced cost/patient for the institution and time and effort for staff. Increased convenience to the patient, as well. My prediction is that almost all patients will be treated with

5 – 10 fractions within the next decade, with courses as short as two weeks for rapidly growing cancers. And cure rates will improve!

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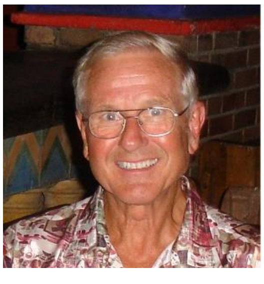
Author Information

Colin Orton is a Past-President and Secretary-General of the IOMP and currently serves as President of the International Medical Physics Certification Board. He has a Ph.D. in Radiation Physics from the University of London and worked as chief medical physicist at New York University, Brown University, and Wayne State University. Throughout his career he taught medical physics and radiobiology to residents, technologists, and graduate students. His involvement in radiobiology began when he first moved from London to New York University in 1966 and was asked to teach the radiobiology course to radiology residents, there being nobody else on the faculty willing to teach it. It was then that he became interested in radiobiological principles of fractionated radiotherapy and developed the Time Dose Fractionation (TDF) mathematical model of radiotherapy that was used until it was replaced by the linear-quadratic model in the early 1980s. Since retiring in 2003 he has continued to teach classes in both medical physics and radiobiology.



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MEDICAL PHYSICS
For the Use of Students and Practitioners of Medicine
(Textbook Published in 1885)

John C. Draper, M.D., L.L.D.
Author
Selection of Illustrations and Discussion
Provided By
Perry Sprawls
Emory University, Atlanta and Sprawls Educational Foundation (www.sprawls.org)

Introduction

Medical Physics, especially as we know it today, is heavily based on ionizing radiation, both x-radiation and from radioactive materials that are used for both diagnostic and therapeutic clinical procedures. This began with Roentgen's discovery and extensive research on the properties of x-ray/Roentgen radiation in 1885 quickly followed by the discovery of radioactivity and the development of medical applications.

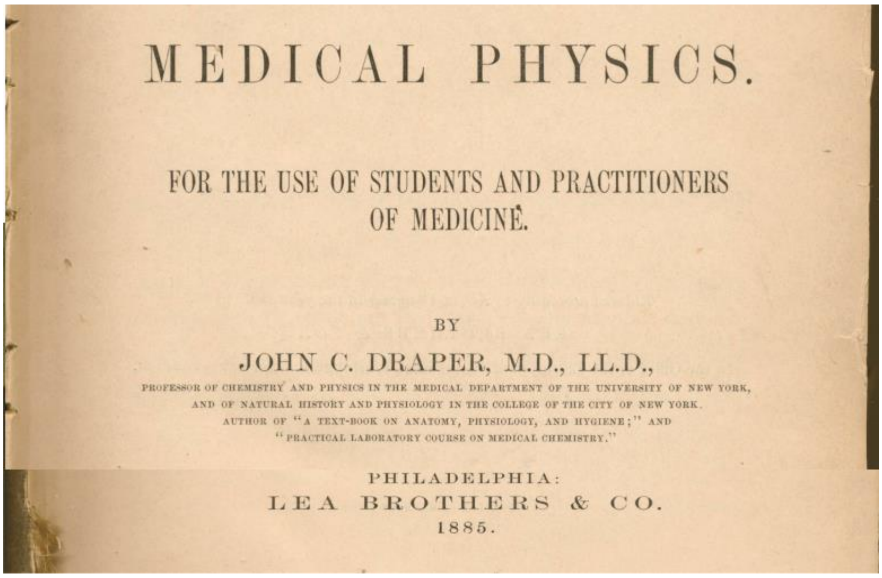
Before that time (1885) *medical physics* was a significant science that applied a wide range of physics phenomena to a better understanding of the living human body, conditions that affect health within a community, and to a variety of medical procedures. This early (before ionizing radiation) field of medical physics is extensively described in the book, Medical Physics by Dr. John Draper published in 1885.

This book of 733 pages provides a comprehensive coverage of virtually all fields of physics known at that time and describes applications related to health and medicine. A major feature is its 377 high-quality illustrations. These enhance conceptual learning and understanding that support/ the application of physics to a wide range of medical and heath related activities. It provides a visual representation of the physical universe rather than a symbolic representation with mathematical symbols and equations. This is the type of knowledge that contributes to the practice of medicine.

Although the title of the book is *Medical Physics*, it provides a comprehensive coverage of all areas of physics supporting the belief that medical practitioners should have a broad knowledge of the physical sciences.

A feature of the book that is of historical significance is that that many of the experiments and apparatus described along with developments and discoveries are identified with the names of the physicists who were the creators.

The images from the book selected for this article are for a few topics to illustrate the state of knowledge at that time and what was being taught. The Figure reference numbers are as they are in the book and not altered for this publication.


MEDICAL PHYSICS.

FOR THE USE OF STUDENTS AND PRACTITIONERS OF MEDICINE.

BY

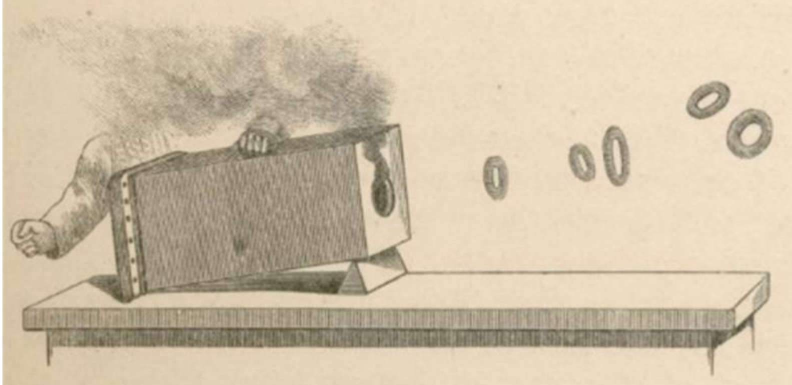
JOHN C. DRAPER, M.D., LL.D.,

PROFESSOR OF CHEMISTRY AND PHYSICS IN THE MEDICAL DEPARTMENT OF THE UNIVERSITY OF NEW YORK, AND OF NATURAL HISTORY AND PHYSIOLOGY IN THE COLLEGE OF THE CITY OF NEW YORK. AUTHOR OF "A TEXT-BOOK ON ANATOMY, PHYSIOLOGY, AND HYGIENE;" AND "PRACTICAL LABORATORY COURSE ON MEDICAL CHEMISTRY."

PHILADELPHIA:
LEA BROTHERS & CO.
1885.

Ultimate Composition of Matter

FIG. 3.

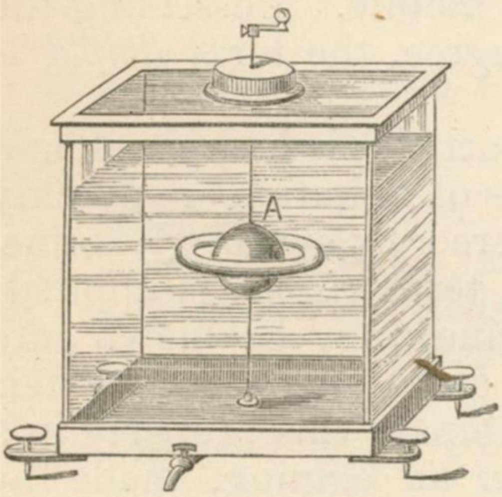


Vortex-rings.

Fig. 3 illustrates a device used to show the formation of a simple circular vortex-ring demonstrating some of its important properties. To set up for a demonstration, ammonia, salt, and sulfuric acid is placed in the box and the combination forms solid sal ammoniac particles that are like smoke. They are visible and suspended in air by fluid-friction. This was used to demonstrate that a vortex had the characteristics and behaved as individual particles. This was especially obvious when two vortexes collided.

Properties of Liquids

FIG. 10.

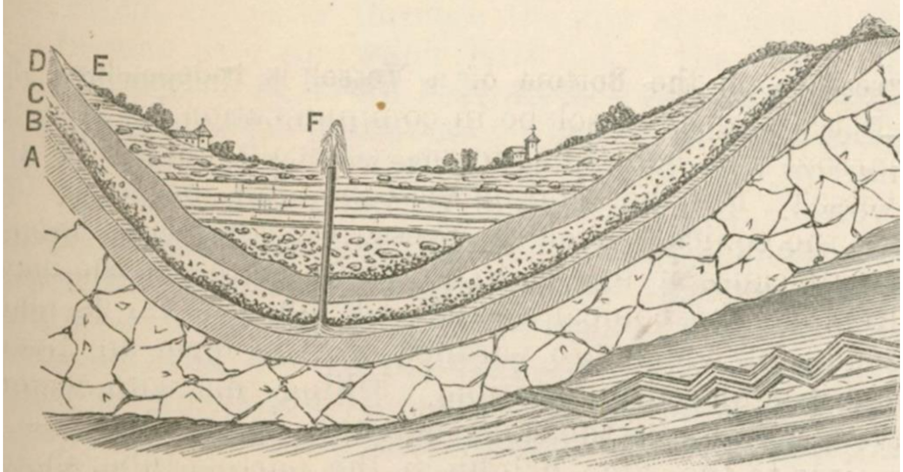


Plateau's experiment.

The experiment shown in Fig. 10 uses a quantity of olive oil suspended in a mixture of water and alcohol that had the same density as the oil. This eliminated any influence of gravity. The oil assumes a spherical shape as show. When it is spun by hand with the handle a satellite ring is formed. This is similar in form to the satellite ring around Saturn.

Hydrostatics

Fig. 15.



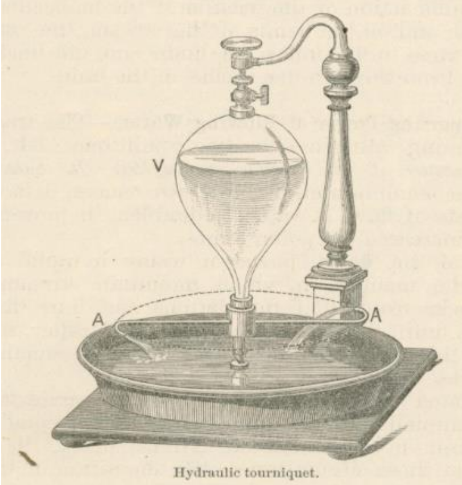
Artesian well.

The sources of water for so-called Artesian wells are often distances away and always at higher elevations as illustrated in Fig. 15. The community health issue is the water is coming and filtered through channels and generally not contaminated as water from shallow wells might be.

A concern at that time was sewerage from toilets was discharged on or near the ground surface and could contaminate water in shallow wells.

Hydrodynamics

Fig. 27.

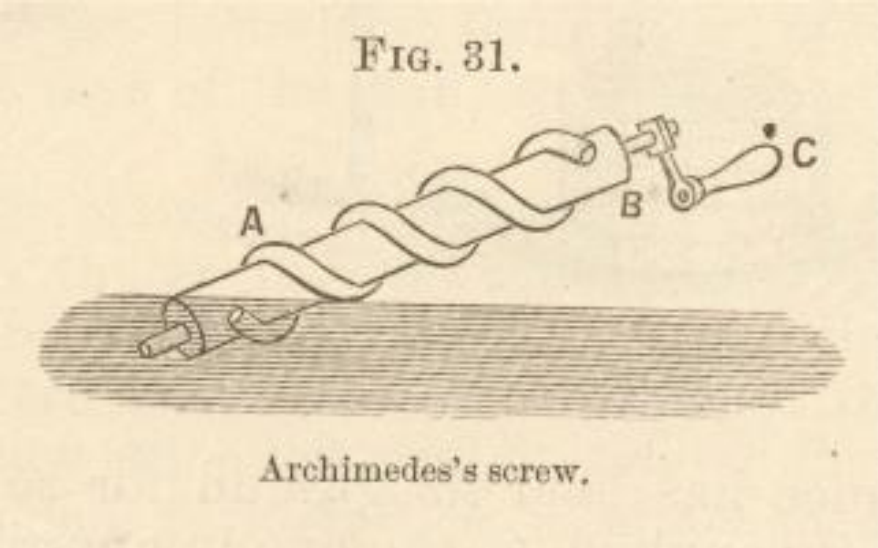


Hydraulic tourniquet.

One of the principles of hydrodynamics, or fluid in motion, is demonstrated in Fig. 27. Specifically, that forces are created by moving fluid. The hydrostatic pressure in the glass container forces water out through the small openings at the end of the tubes.

The acceleration of the water to pass through the small openings creates a force that rotates the apparatus.

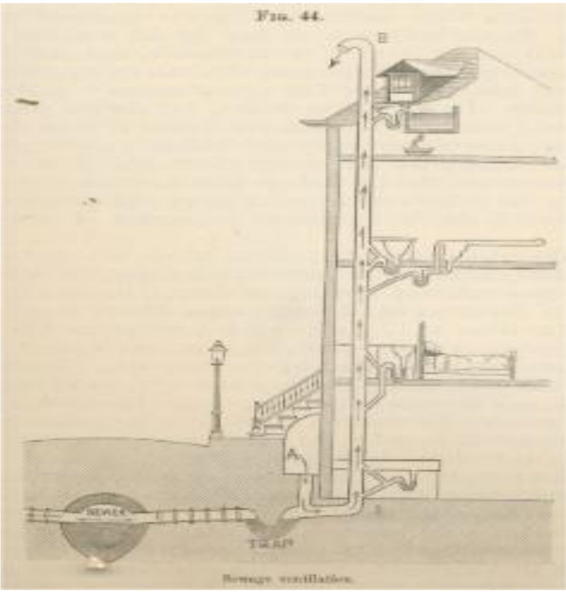
Hydraulics



Archimedes's screw.

Hydraulics, the movement of fluids, is achieved with many different devices, including pumps, turbines, etc. One method uses an Archimedes's screw illustrated in Fig. 31. It was used extensively, especially in Europe, to pump water, drain flooded areas, and to move sewage.

It is relatively simple in design and economical to use, often powered by windmills.

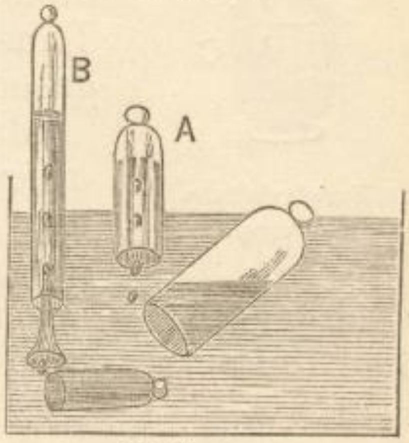


Sewage ventilation.

The significance of properly designed and constructed sewer systems is emphasized here in Fig. 44. A specific Health issue illustrated here is proper venting to protect against the buildup of gases in the living areas.

Pneumatic Apparatus

FIG. 51.



Pouring gas.

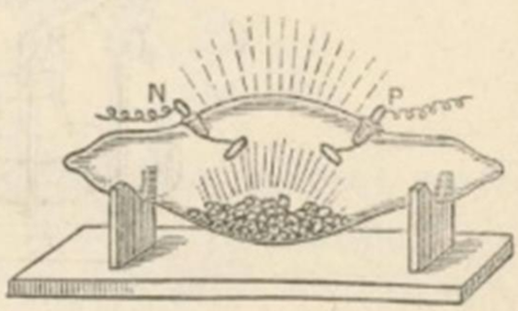
It is generally easy to pour a liquid from one container to another with the help of gravity. How do you pour a gas? One method used in the physics laboratory is illustrated here. It is done in a large container of water. An empty container, with respect to gas, is filled with water and with the opening down in the larger water container.
When a gas is poured from another container it displaces the water as it bubbles up into the receiving container.

Properties of Radiant Matter

In a lecture by Faraday in 1816, we find the first use of the term *radiant matter*. In 1819, Faraday says, "matter may be classed into four states, solid, liquid, gaseous, and radiant. Crookes contributed to the concept of radiant matter by demonstrating the passage of a form of matter through tubes in which the gas molecules had been removed down to approximately one millionth of an atmosphere. A major issue was to show that radiant matter was very different from gas molecules and had different properties.

Added Note: The electron (a form of radiant matter) was discovered by the English physicist J.J. Thomson in 1897.
It had been observed that some substances, including several precious stones would emit visible light when submitted to the action of an electric discharge.

FIG. 95.

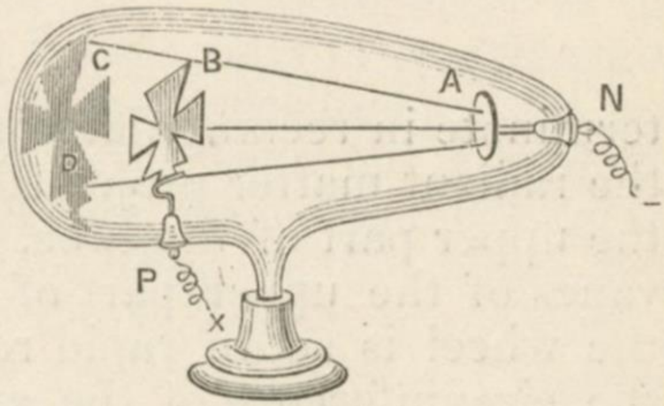


Ruby tube.

Shown here in Fig. 95 is the Ruby Tube developed by Professor Crookes. Various substances are placed in the highly evacuated (about one millionth of an atmosphere). When the electrodes are connected to a coil providing a high voltage the substances glow with colors that are characteristic of each material. Rubies emit a red color and diamonds emit a variety of colors.

The glass tube itself also emits light with the color depending on the source of the glass. English glass emits a blue light and the German glass that was most frequently used for tubes emitted a bright apple-green color.

FIG. 97.

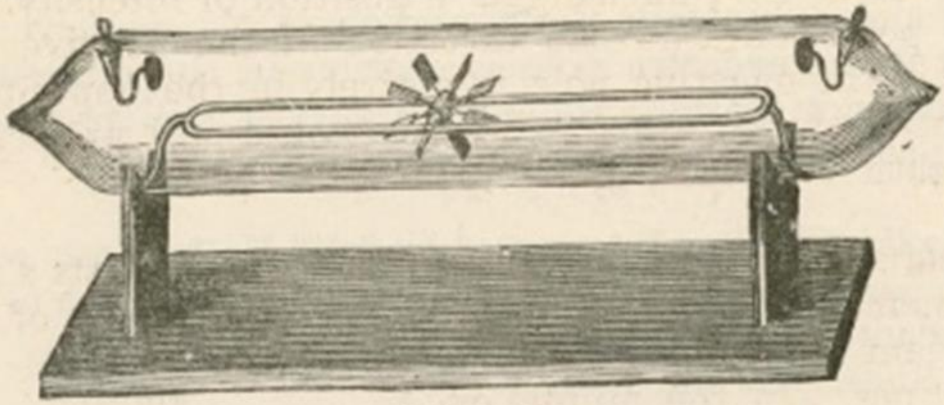


Shadow tube.

The tube shown in Fig. 97 was used to demonstrate that radiant matter traveled in straight lines and could cast a shadow. When the two electrodes in the tube were connected to a coil providing a high voltage the large end of the tube glowed where it was exposed to the radiant matter. The metal star mounted in the tube intercepted the radiant matter and cast a shadow.

Added Note: It would be discovered many years later that this type of tube connected to a high-voltage source was producing x-radiation.

FIG. 98.

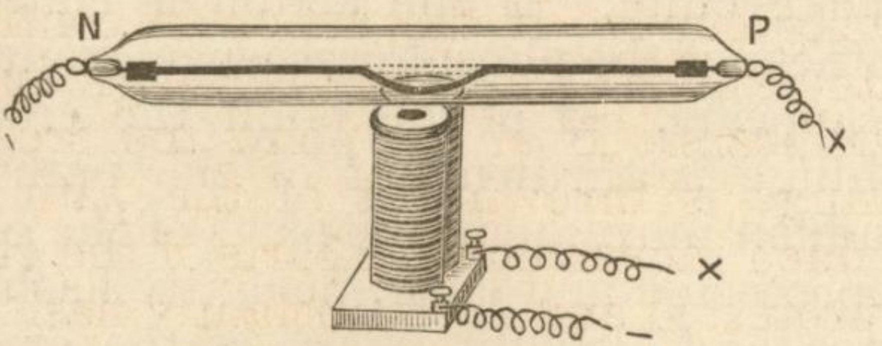


Railway tube.

The apparatus shown in Fig. 98 was used by Professor Crookes to demonstrate that radiant matter could exert forces and names this the Railway Tube. It consists of a track running between the two electrodes at the ends of the tube.

A small lite-weight paddle wheel is placed on the track so that the paddles in the upper position are inline between the two electrodes. When the electrodes are connected to an electrical source the paddle wheel rotates and moves along the track away from the negative terminal. Demonstrating that a beam of radiant matter is flowing from the negative to the positive electrode.

FIG. 99.



Action of magnet on low vacuum tube.

The tube shown in Fig. 99 was used to demonstrate that radiant matter could be deflected with a magnet. Within the tube there was a partial vacuum leaving sufficient gas to ionize and glow along the path of radiant matter between the two electrodes.

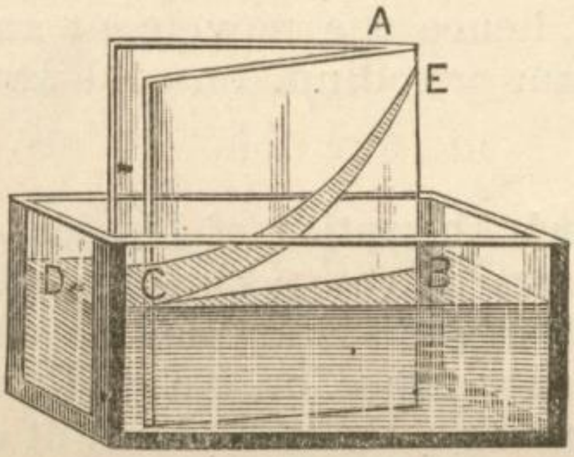
FIG. 101.

Radiant matter produces heat where it strikes.

The tube shown in Fig. 101 was used to demonstrate that radiant matter produced heat when it was absorbed in a material. It contained a small platinum plate at the positive terminal (B) and a focused cup at the negative terminal as shown. When it is connected to an electrical source radiant matter is focused on the platinum plate heating which becomes red-hot. The heat radiates to the glass tube causing it to become warm.

Molecules Of Two Media, One Set Moving

FIG. 129.

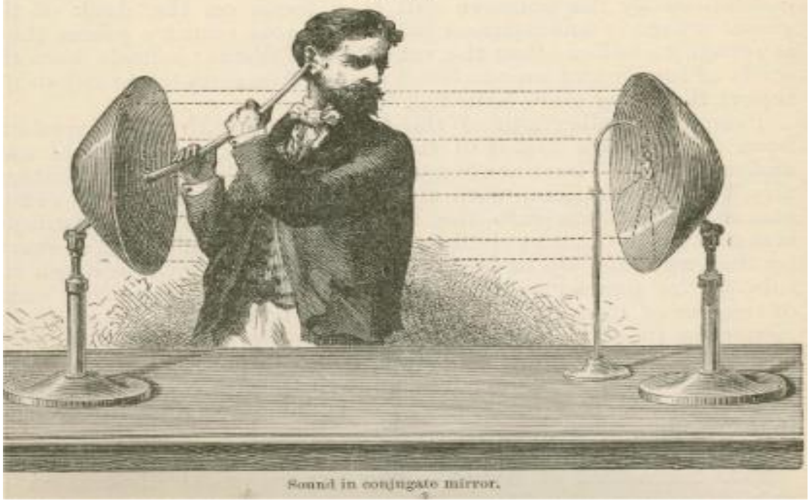


Capillarity between inclined plates.

The apparatus shown in Fig. 129 was used to demonstrate capillary action that occurs between the surfaces of a solid and a liquid. Two glass plates are separated with a wedge shape as shown and placed in a tank of water. The water is pulled up by capillary action between the solid and liquid media. It is pulled to the greatest height where the glass plates are the closest.

General Properties of Sound

FIG. 158.

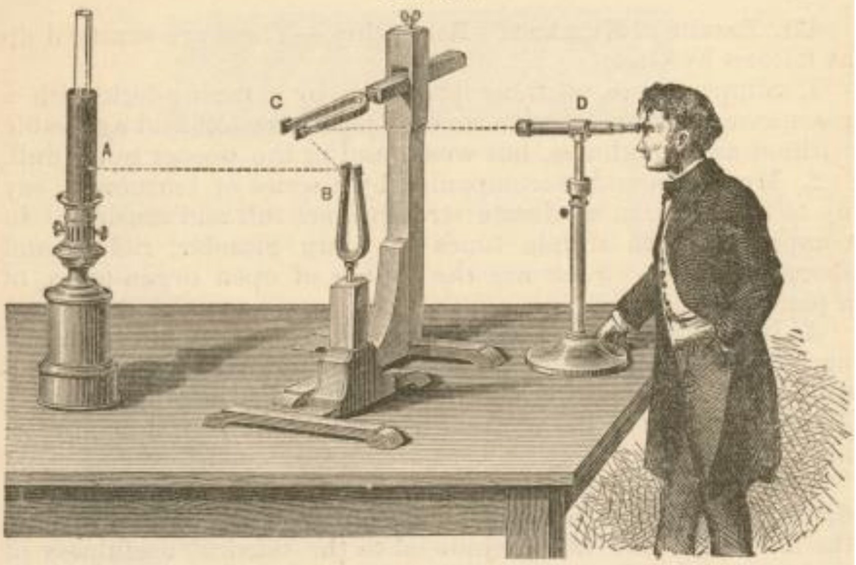


Sound in conjugate mirror.

Figure 158 is a demonstration of the reflection of sound between two parabolic mirrors. A watch is placed at the focus of the mirror on the right. The sound is then reflected in parallel lines to the mirror on the left. It is then re-focused where it can be conducted to the ear as illustrated.

Analysis And Synthesis of Sound

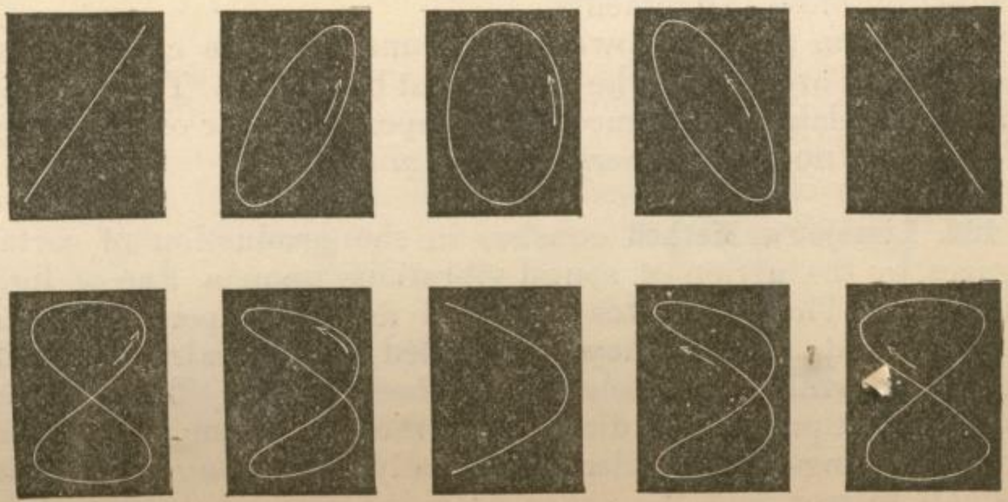
FIG. 182.



Lissajou's method.

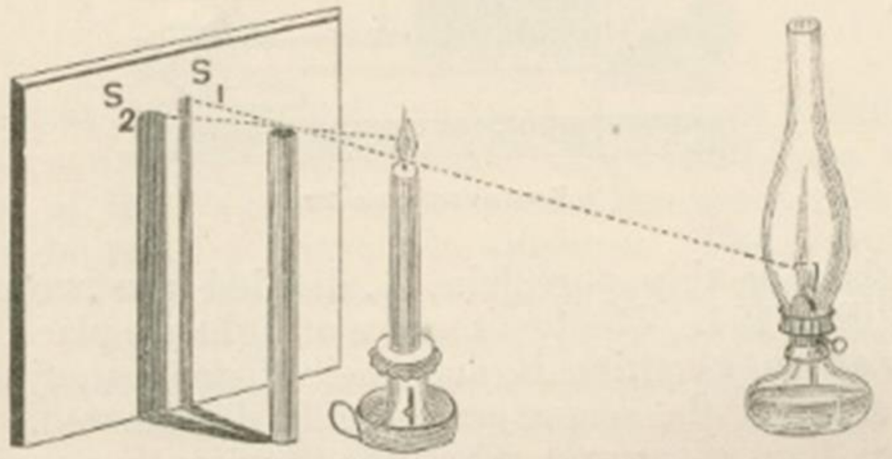
The apparatus shown in Fig. 182 was used to demonstrate the combined effect of resonant vibrations in different directions and the formation of Lissajou's curves. Small mirrors are mounted on the two tuning forks. A small point source of light is viewed with a telescope along a path through the two mirrors. When the tuning forks are not vibrating, a small point of light is observed. When the forks are vibrating various patterns are formed and recorded on photographic paper as illustrated in Figure 183 below. The shapes depend on the frequency and phase relationships between the two vibrating forks.

FIG. 183.



Transmission, Absorption, And Intensity of Light

FIG. 196.

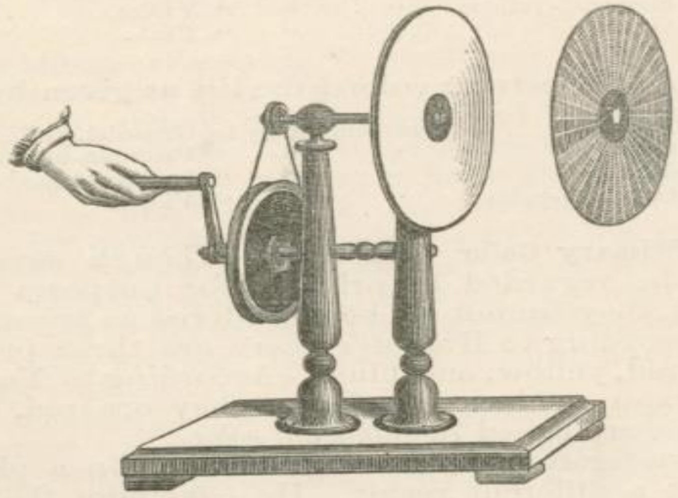


Illumination photometer.

Rumford's photometer illustrated in Fig. 196 was one method used to measure the intensity of a light source. An opaque rod is located a short distance in front of a screen as shown. The two light sources that are to be compared are moved until their shadows appear with the same intensity. The intensity of each is proportional to the square of the distance between the light source and screen.

Chromatics

FIG. 226.



Rotating disk.

Newton's rotating disk shown in Fig. 226 is one method used to demonstrate the composition of light as a mixture of different colors. Disks divided into segments of various colors are mounted on the spinning apparatus. When they are spun at a high speed the composite color is observed. This would be white when the segments of the disk contain the spectrum of colors that are in white light.

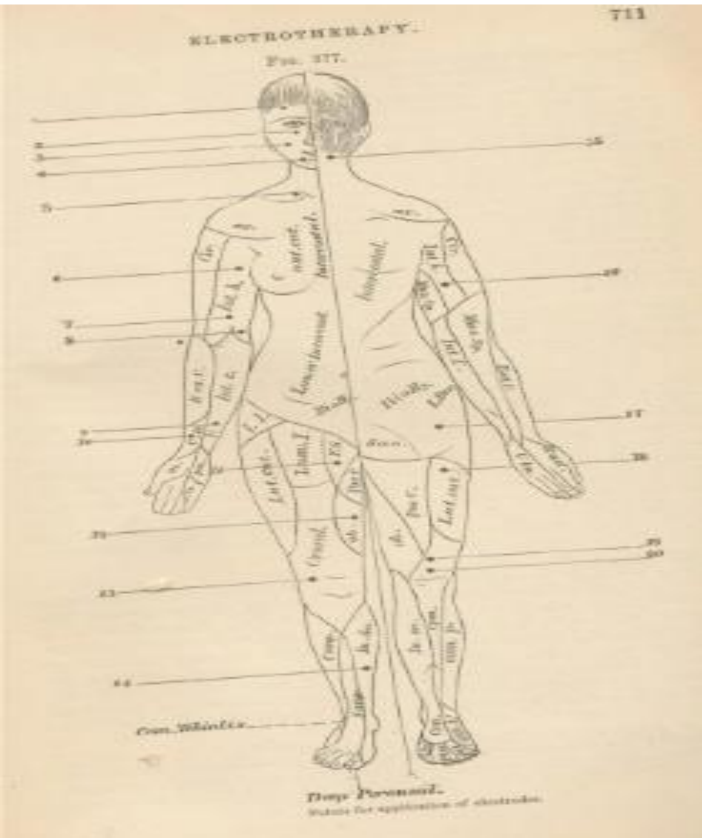
Faradaic or Induced Currents

FIG. 363.

Medical magnetoelectric machine.

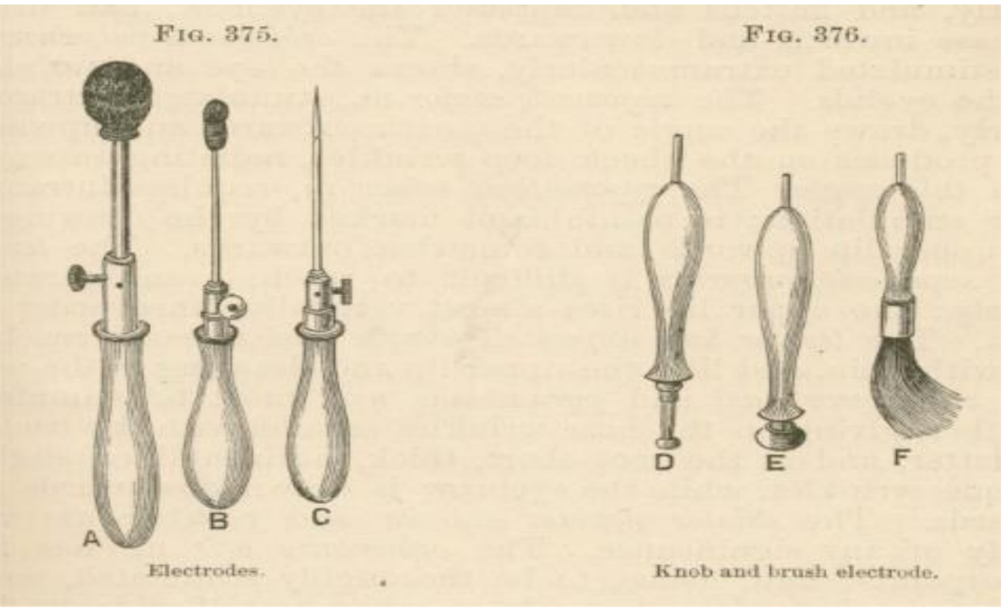
The principle of magnetic induced currents was used to explain the operation of the “magnetoelectric” machine shown in Fig. 363. It contains a large horse-shoe magnet (A) and a mechanism for rotating a small metal object between the magnetic poles. As the magnetism in the object fluctuates with the rotation, an electric current is induced in a coil around the rotating object. The machine was used to pass electrical currents through the human body for medical purposes.

Electrobiology; Elecrophysioloy And Elecrotherapy



Electrobiology, the interaction of electricity with living organisms, was a major field of interest within the scope of medical physics. It generally consisted of two areas of specialization, electrophysiology, the study of natural electricity within living organisms, and electrotherapy, the application of electricity to the human body for medical purposes. Fig. 377 is a detailed diagram showing where to apply electrodes to treat specific conditions.

A variety of electrodes for different medical applications are shown in Figs. 375 and 376 below.

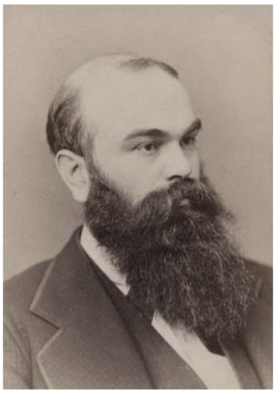


Summary and Looking Back in Time

The textbook, *Medical Physics*, authored by John C. Draper, M.D., L.L.D. and published in 1885, provides a comprehensive description of the field of physics as it was known and practiced at that time in history. The purpose of the book was to provide medical professionals and students with an understanding and knowledge of all physical principles with an emphasis on physics that applied to the living human body and function (vision, hearing, etc.), public health, and treatment methods. With its many high-quality illustrations, it visually connects readers with a variety of experiments and demonstrations that enhanced the learning process.

The illustrations selected and discussed here give emphasis on some of the classic experiments and demonstrations from the past, the great interest among physicists in "radiant matter", and physics based therapeutic methods at that time in history.

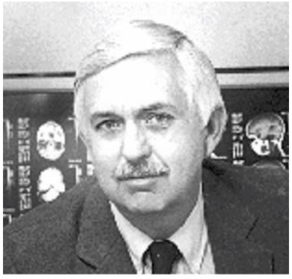
The interest and experiments with "radiant matter" is especially significant. This was to be the foundation for the discovery of x-radiation by Roentgen in 1885 that was to "give birth" to the field of medical physics as we know and practice it today



Book Author

John Christopher Draper, M.D.,L.L.D. (March 31, 1835 – December 20, 1885), https://en.wikipedia.org/wiki/John_Christopher_Draper, was an American chemist and surgeon and author of several major textbooks of the time. His book, *Medical Physics*, published in 1885 was a major contribution to the naming, defining, and establishing of the field of *Medical Physics*.
It emphasized the value of a comprehensive understanding and knowledge of physics for medical practitioners and students.

Article Author



Dr. Perry Sprawls

Perry Sprawls, Ph.D., is a clinical medical physicist and educator,, with a major interest in the preservation of the history and heritage of medical physics and related medical applications. Links to his other historical publications are on the website www.sprawls.org . Contact: sprawls@emory.edu

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MONUMENT TO THE X-RAY AND RADIUM MARTYRS OF ALL NATIONS

Perry Sprawls

Emory University, Atlanta and Sprawls Educational Foundation (www.sprawls.org)

The Monument on the grounds of St. Georg (St George's) Hospital (now the *Asklepios Klinik St Georg*) in Hamburg unveiled on 4 April 1936 by the *Deutsche Röntgengesellschaft* (the Röntgen Society of Germany)

Inscription

This monument is a memorial to those who lost their lives because of exposure to ionizing radiation relating to their professional activities. The inscription (English Translation) reads:

To the Roentgenologists and radiologists of all nations,
To the doctors, physicists, chemists, technicians, laboratory assistants and nurses
who sacrificed their lives in the fight against disease.
They were valiant pioneers in the effective
and safe use of X-rays and radium in medicine.
Immortal is the glory of the work of the dead.

History

When the monument was created in 1936 it displayed 169 names on the tall column. This included Maria Skłodowska-Curie (1867-1934). In 1959 additional stones were added with a total of 359 names.

The names of the martyrs along with links to other related publications can be found in the reference below.

Reference

Monument to the X-ray and Radium Martyrs of All Nations.
https://en.wikipedia.org/wiki/Monument_to_the_X-ray_and_Radium_Martyrs_of_All_Nations#:~:text=The%20Monument%20to%20the%20X,X%2Drays%2C%20in%20medicine.

Author Information

Perry Sprawls, Ph.D., is a clinical medical physicist and educator with a major interest in the preservation of the history and heritage of medical physic and related medical applications.
Links to his other historical publications are on the website. www.sprawls.org
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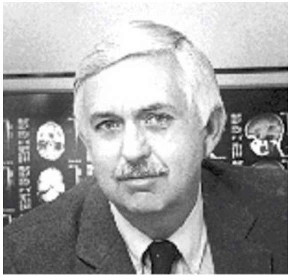

Dr. Perry Sprawls