Clinically Focused Physics Education

The Foundation for Image Quality and

Effective Dose Management

Perry Sprawls, Ph.D.
Distinguished Emeritus Professor
Emory University
and
Sprawls Education Foundation
http://www.sprawls.org
Clinically Focused Physics Education

Clinical Radiology

Effective Knowledge Structures

Levels of Learning

DO

LEARN

Learning Activities

Effectiveness and Efficiency

RESOURCES
Today

Our Clinical Physics Activities

Quality Assurance
Consulting
Teaching
Clinical Medicine

Imaging

Radiation Therapy

Physics

The Foundation Science
Effective and Safe Clinical Procedures

Imaging

Radiation Therapy

Require an extensive knowledge of

Applied Physics

and

The Associated Technology
Who needs a knowledge of Physics applied to clinical imaging?

Radiologists, Residents and Fellows

Technologists

Medical Physicists

Each provides unique challenges and opportunities.
Physics Learning Objectives for Radiologists

Image Physical Characteristics

- Identify
- Relationship to Visibility
- Evaluate
- Control and Optimize
- Risk
- Anatomy and Pathology

Sprawls
Why an Evolving Model?

Three Dynamics....

1. Rapidly expanding **NEEDS** for physics knowledge.

2. Expanding availability of educational **RESOURCES**.

3. Better knowledge of the learning and teaching process.
Continuing Growth in the Need for Physics Knowledge

Capability and Complexity

CT
MRI
Radionuclide Imaging
Mammography
Digital

Time
Digital Resources to Enrich Learning Activities

The Web
Connecting and Sharing

Textbooks Modules
Visuals
Clinical Images
Modules
References Teaching Files

Classroom
Clinical Conference
Small Group
“Flying Solo”
Clinically Focused Physics Education

Classroom  Clinical Conference  Small Group  "Flying Solo"

Learning Facilitator "Teacher"  Individual and Peer Interactive Learning

Each type of learning activity has a unique value.
Clinically Focused Physics Education

Classroom
Clinical Conference
Small Group
“Flying Solo”

Learning Facilitator
“Teacher”

The Goal..

Increase the EFFECTIVENESS of each type of learning activity with the necessary resources and understanding of the process by the Learning Facilitators.

Sprawls
The Barrier

Physics Education  
Clinical Imaging

Efficiency
Location, Resources, Human Effort, Cost

Limited Experience
Learning is....

Building knowledge structures in the brain

Image: UCDavis
The Brain...

Structure and Function

Image: AMA
Zull’s Model of Brain Function

James Zull, Ph.D.
Professor of Biology
Professor of Biochemistry
Director of University Center for Innovation in Teaching and Education
Case Western Reserve

Reference:
THE ART OF CHANGING THE BRAIN
Kolb’s Experiential Learning Model

1. Concrete experience
2. Observation and reflection
3. Forming abstract concepts
4. Testing in new situations

David A. Kolb, Ph.D.
Professor of Organizational Behavior
Case Western Reserve

Website: http://www.learningfromexperience.com
Brain Functions for Learning Physics

Control

Sensory

Motor

Emotions

Back Integrative Cortex

Records of the Past

Reflection

Frontal Integrative Cortex

Preparation for the Future

Hypotheses

Sprawls
Brain Functions for Learning Physics

Control

Sensory

Back Integrative Cortex

Records of the Past
Knowing

Motor

Frontal Integrative Cortex

Preparation for the Future
Doing

Emotions

Sprawls
Brain Functions for Learning Physics

Control

Sensory

Back Integrative Cortex

Records of the Past

Knowing

Frontal Integrative Cortex

Preparation for the Future

Doing

Motor

Emotions

Balanced Education

Sprawls
Forming Knowledge Structures

Physical Universe

Radiation
Electrons
Magnetic
Atomic
Nuclear

Sensory

Back Integrative Cortex

Invisible Physical Objects

Sprawls
Forming Knowledge Structures

Physical Universe

Radiation
Electrons
Magnetic
Atomic
Nuclear

Back Integrative Cortex

Sensory

Invisible

Physical Objects

Visuals

33 keV
Iodine

Binding Energy
Back Integrative Cortex

Integrating experience into existing knowledge structure

Sensory

Meaning
Back Integrative Cortex
Integrating experience into existing knowledge structure

Sensory

Meaning
Back Integrative Cortex
Integrating experience into existing knowledge structure

Medical Knowledge
Back Integrative Cortex
Integrating experience into existing knowledge structure

The image is the connection
Back Integrative Cortex

Integrating experience into existing knowledge structure

The image is the starting point for learning physics
Computed Tomography

Image Characteristics and Quality

Radiation Dose

Imaging Protocols

Technology

Science

Sprawls
COMPUTED TOMOGRAPHY
QUALITY CHARACTERISTICS

- SPATIAL
- ARTIFACTS
- DETAIL (BLURRING)
- CONTRAST SENSITIVITY
- NOISE

PROTOCOL FACTORS
- SLICE TH.
- MAS
- Matrix

OPERATION
Brain Functions for Learning Physics
Active Experimentation and Testing

Control
- Back Integrative Cortex: Records of the Past Knowing Reflection
- Frontal Integrative Cortex: Preparation for the Future Doing Hypotheses

Emotions

Sensory

Interact and Affect

Sense and Experience

Observe

Physical Universe

Sprawls
The Learning Environment

Control

Back Integrative Cortex

Records of the Past
Knowing Reflection

Frontal Integrative Cortex

Preparation for the Future
Doing Hypotheses

Sensory

Emotions

Sprawls
Rich Learning Environments

Records of the Past
Knowing Reflection

Preparation for the Future
Doing Hypotheses

Sprawls
Challenging Learning Environments

Control

Sensory Back Integrative Cortex

Records of the Past
Knowing Reflection

Frontal Integrative Cortex

Preparation for the Future
Doing Hypotheses

Emotions

Sprawls
Robert Gagne (1916-2002)

Best known for his Nine Events of Instruction

The Gagne assumption is that different types of learning exist, and that different instructional conditions are most likely to bring about these different types of learning.

Gagné was also well-known for his sophisticated stimulus-response theory of eight kinds of learning which differ in the quality and quantity of stimulus-response bonds involved. From the simplest to the most complex, these are:

- signal learning (Pavlovian conditioning)
- stimulus-response learning (operant conditioning)
- chaining (complex operant conditioning)
- verbal association
- discrimination learning
- concept learning
- rule learning
- and problem solving.
Gagne’s Hierarchy of Learning

- Problem Solving
- Rule Learning
- Concept Learning
- Discrimination Learning
- Verbal Association
- Chaining
- Stimulus Response
- Signal Learning
Edgar Dale (1900-1985)
Educationalist who developed the famous Cone of Experience theory
Cone of Experience for Medical Imaging Education

- **Verbal**
- **Symbols**
- **Equations**
- **Sketches**
- **Visuals** with Expert Guidance
- **Simulation**
- **Physical Reality**
Cone of Experience for Medical Imaging Education

EFFECTIVENESS

LOW

HIGH

EFFICIENCY

HIGH

LOW

VERBAL

SYMBOLS

EQUATIONS

SKETCHES

VISUALS

Clinical Images and Graphics

VISUALS

With Expert Guidance

SIMULATION

PHYSICAL REALITY

Sprauls
Cone of Experience for Medical Imaging Education

LEARNING OUTCOMES

Define
List
Describe
Explain
Demonstrate
Apply
Practice
Analyze
Create
Evaluate

VERBAL
SYMBOLS
EQUATIONS
SKETCHES
VISUALS
Clinical Images and Graphics
VISUALS
With Expert Guidance
SIMULATION
PHYSICAL REALITY

Sprawls
Technology Enhanced Learning and Teaching

Experience

Level

Learning

VERBAL
SYMBOLS
EQUATIONS
SKETCHES
VISUALS
Clinical Images and Graphics
VISUALS
With Expert Guidance
SIMULATION
PHYSICAL REALITY

Problem Solving
Rule Learning
Concept Learning
Discrimination Learning
Verbal Association
Chaining
Stimulus Response
Signal Learning

Sprawls
Clinically Focused Physics Education

Classroom

Clinical Conference

Small Group

“Flying Solo”

Highly Efficient
For General Physics and Related Topics

Highly Effective
Clinically Rich Learning Activities

Visuals, Images, Online Modules, Resources, and References

Sprawls
Physics Education

Images
- Contrast
- Detail
- Noise
- Artifacts
- Spatial

Characteristics and Comparison of Modalities

Radiation
- Radiation for Imaging
- Quantities and Units
- X-Ray Production
- Radioactivity
- Interactions

Digital Image Structure and Characteristics

Clinical
- X-Ray Image Formation
- Radiographic Receptors
- Radiographic Detail
- Fluoroscopic Systems
- CT Image Formation
- CT Image Quality and Dose Optimization
- Radionuclide Imaging, SPECT, PET
- MRI
- Ultrasound

Radiation Safety
- Biological Effects
- Personnel Protection
- Patient Dose Management
Rich Classroom and Conference Learning Activities

Learning Facilitator "Teacher"

- Organize and Guide the Learning Activity
- Share Experience and Knowledge
- Explain and Interpret What is Viewed
- Motivate and Engage Learners

Visuals

Representations of Reality

Sprawls
Visuals for Learning and Teaching

The Imaging Process

Clinical Images

The Three Phases of CT Image Formation

Scan and Data Acquisition

Image Reconstruction

Digital/Analog Conversion and Display Control

Major Control Factors

Sprawls

Sprawls
In Partnership with Other Medical Physics Teachers to be More Effective and Efficient in Providing Medical Imaging Education
# Mammography Physics and Technology

for effective clinical imaging

Perry Sprawls, Ph.D.

To step through module, [CLICK HERE.](#)

To go to a specific topic click on it below

<table>
<thead>
<tr>
<th>Imaging Objectives</th>
<th>Rhodium Anode</th>
<th>Blurring and Visibility of Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility of Pathology</td>
<td>KV Values for Mammography</td>
<td>Focal Spot Blurring</td>
</tr>
<tr>
<td>Image Quality Characteristics</td>
<td>Scattered Radiation and Contrast</td>
<td>Receptor Blurring</td>
</tr>
<tr>
<td>Not a Perfect Image</td>
<td>Image Exposure Histogram</td>
<td>Composite Blurring</td>
</tr>
<tr>
<td>Mammography Technology</td>
<td>Receptor &amp; Display Systems</td>
<td>Magnification Mammography</td>
</tr>
<tr>
<td>Imaging Technique Factors</td>
<td>Film Contrast Transfer</td>
<td>Mean Glandular Dose</td>
</tr>
<tr>
<td>Contrast Sensitivity</td>
<td>Film Contrast Factors</td>
<td></td>
</tr>
<tr>
<td>Physical Contrast Compared</td>
<td>Film Design for Mammography</td>
<td></td>
</tr>
<tr>
<td>Factors Affecting Contrast Sensitivity</td>
<td>Controlling Receptor (Film) Exposure</td>
<td></td>
</tr>
<tr>
<td>X-Ray Penetration and Contrast</td>
<td>Film Processing</td>
<td></td>
</tr>
<tr>
<td>Optimum X-Ray Spectrum</td>
<td>Variations in Receptor Sensitivity</td>
<td></td>
</tr>
<tr>
<td>Effect of Breast Size</td>
<td>Film Viewing Conditions</td>
<td></td>
</tr>
</tbody>
</table>
The x-ray beam spectrum is one of the most critical factors that must be adjusted to optimize a procedure with respect to contrast sensitivity and dose.

We can think of it as a three-step procedure:
1. Select the appropriate anode (moly or rhodium)
2. Select the appropriate filter (moly or rhodium)
3. Select the appropriate KV (in the range 24 kV to 32 kV)

Increasing the KV has two effects on the x-ray beam. It increases the efficiency and output for a specific MAS value and it shifts the photon energy spectrum forward so that the beam becomes more penetrating.

While a more penetrating beam does reduce contrast sensitivity it is necessary when imaging thicker and more dense breast. Therefore, compressed breast thickness is the principal factor that determines the optimum KV.

Mammography systems have indicators that display the thickness of the compressed breast. This along with a general assessment of breast density is used to manually select an optimum KV either from experience or an established technique chart.

The general goal is to increase the KV as necessary to keep the exposure time, MAS, and dose to the breast within reasonable limits as breast thickness increases.
CT Image Characteristics

A

B

C

Reference
CT Image Characteristics

Spatial

Detail

Artifacts

Noise

Contrast Sensitivity

Major Protocol Factors

KV

Pitch

Slice Th.

Window Width

MA

Beam Wid.

FOV

Window Level

Time

Filter

Matrix

Zoom

Sprawls
The Three Phases of CT Image Formation

Scan and Data Acquisition

Image Reconstruction

Digital/Analog Conversion and Display Control

Major Protocol Factors

KV
MA
Beam Wid.

Pitch

Slice Th.
FOV
Matrix
Filter

Window Width
Window Level
Zoom

Sprawls
CT Slice Divided into Matrix of Voxels

Field Of View (mm)

Matrix Size (voxels/pixels)

Slice Thickness (mm)

Voxel Size Controlled By

FOV ÷ Matrix = Slice Th.
The Quantum Structure of the X-ray Beam

Photons
X-ray Photons Interact With Tissue in A Voxel

**Radiation Dose**
determined by
Concentration of
Absorbed Energy
per voxel

**Image Noise**
determined by
Number of Photons
per voxel

Dose is increased by increasing number of photons.

Noise is reduced by increasing number of photons.
SPIRAL SCAN

CONTINUOUS

Distance per Revolution

PITCH = \frac{D}{W}

Beam Width
Decreasing Noise

Requires Increased Photons Absorbed Per Voxel

Produces Increasing Dose
Effect of Matrix Size on Image Noise

Small Matrix

Large Voxels
Low Noise

Large Voxels
High Noise

The same radiation dose for both images.
Factors That Determine Image Noise

- **KV**: Kilovoltage
- **MA**: Milliampere seconds
- **Time**: Exposed time
- **Pitch**: Angle of rotation

Concentration of absorbed photons and energy at each location in the body tissue

- **Filtered Back Projection**
- **Filter**
- **Voxel Size**: Determines the number of photons
- **Slice Th.**
- **FOV**: Field of view
- **Matrix**

Digital Image
Two Major Image Quality Goals

High Detail

Low Noise

Voxel Size

Small

Large

FOV

Matrix

Slice Th.

Protocol Factors
Relationship of Radiation Dose to Image Detail

Lower Dose

When detail is increased by

- Decreasing Slice Th.
- Increasing Matrix
- Decreasing FOV

Noise Increases
Because of decreased voxel size

Higher Dose

Dose must be increased to reduce noise.

Sprawls
Factors That Determine Image Detail (Sources of Blurring)

Scan Data → Filtered Back Projection → Digital Image

- Focal Spot
- Pitch
- Beam Wid.

- Filter
- Voxel Size
- Slice Th.
- FOV
- Matrix

Detector
Reconstruction Filter Kernels

Filtered Back Projection

Noise Reduction
- Filtered
- Standard
- Increased Blurring

Enhance Detail
- Filtered
- Standard
- Increased Noise

Reference Image

(Effects exaggerated for illustration here)
Scan Data Set

Focal Spot

Pitch

Revolution "Tracks"

Detector

Beam Wid.
The Values We Hold

The PHYSICIST is the TEACHER.

TECHNOLOGY is the TOOL that can be used for effective and efficient teaching.

Technology should be used to enhance human performance of both learners (residents, students, etc.) And teachers.
Clinically Focused Physics Education

Website

http://www.sprawls.org/clinphys