

TRANSFER OF STUDENTS' LEARNING ABOUT X-RAYS AND COMPUTER-ASSISTED  
TOMOGRAPHY FROM PHYSICS TO MEDICAL IMAGING

by

SPARTAK A. KALITA

M. Sc., Moscow Institute of Physics and Technology, 1994

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Physics  
College of Arts And Sciences

KANSAS STATE UNIVERSITY  
Manhattan, Kansas

2008

## **Abstract**

In this study we explored students' transfer of learning in the X-ray medical imaging context, including the X-ray-based computer-assisted tomography (or CAT). For this purpose we have conducted a series of clinical and teaching interviews. The investigation was a part of a bigger research effort to design teaching-learning materials for pre-medical students who are completing their algebra-based physics course. Our students brought to the discussion pieces of knowledge transferred from very different sources such as their own X-ray experiences, previous learning and the mass media. This transfer seems to result in more or less firm mental models, although often not internally consistent or coherent.

Based on our research on pre-med students' models of X-rays we designed a hands-on lab using semi-transparent Lego bricks to model CAT scans. Without "surgery" (i.e. without intrusion into the Lego "body") students determined the shape of an object, which was built out of opaque and translucent Lego bricks and hidden from view. A source of light and a detector were provided upon request. Using a learning cycle format, we introduced CAT scans after students successfully have completed this task. By comparing students' ideas before and after teaching interview with the groups of 2 or 3 participants, we have investigated transfer of learning from basic physics and everyday experience to a complex medical technology and how their peer interactions trigger and facilitate this process.

During the last phase of our research we also introduced a CAT-scan simulation problem into our teaching interview routine and compared students' perception of this simulation and their perception of the hands-on activity.

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# Table of Contents

List of Figures .....	x
List of Tables .....	xi
Preface.....	xii
CHAPTER 1 Motivation and Goals .....	1
1.1 Physics Education for Pre-Med Students.....	1
1.2 Modern Miracle Medical Machines Project .....	2
1.3 X-rays and CAT-scans in MMMM .....	3
1.4 Research Purposes and Questions.....	3
1.5 Broader Impact .....	4
1.6 Roadmap of This Dissertation .....	4
CHAPTER 2 Predecessors and Context .....	5
2.1 Chapter Overview .....	5
2.2 Constructivist Approach .....	5
2.2 Transfer of Learning .....	14
2.3 Knowledge structures and mental models .....	17
2.3.1 P-Prims.....	18
2.3.2 The conceptual resources.....	18
2.3.3 The Facets .....	19
2.3.4 The coordination classes .....	19
2.3.5. The mental models.....	19
2.4 Historical Overview of X-rays.....	22
2.5 Historical Overview of Medical Imaging .....	24
2.5.1. Four generations of CT scanners .....	27
CHAPTER 3 Methodology.....	29
3.1 Chapter Overview .....	29
3.2 Qualitative Research.....	29
3.2 Phenomenology and Phenomenography.....	33
3.2.1. Phenomenology.....	33

3.2.2 Phenomenography.....	34
3.4 Interview as a Research Tool.....	35
3.4.1 Interviews In General.....	35
3.4.2 Clinical Interview.....	38
3.4.3 Teaching Interview .....	39
CHAPTER 4 Clinical Interviews.....	43
4.1 Chapter Overview .....	43
4.2 General Research Settings .....	43
4.2.1 College-Level Physics Classes Taken By Our Participants.....	43
4.2.1.1 Concepts of Physics .....	43
4.2.1.2 General Physics.....	44
4.2.1.3 Engineering Physics.....	44
4.2.2 Choosing the Participants .....	44
4.3 Settings of the interviews.....	45
4.3.1 General interview settings.....	45
4.3.2 Specific interview settings .....	46
4.4 Types of questions .....	47
4.5 Research Phases 1 and 2 .....	48
4.5.1 Development of the Preliminary Protocol .....	48
4.5.2 Demographics of the students interviewed during the Phases 1 & 2.....	48
4.5.3 Designing the interview protocol for the Phase 1 .....	49
4.5.4 Changes in the interview protocol for the Phase 2.....	51
CHAPTER 5 Teaching Interviews.....	53
5.1 Chapter Overview .....	53
5.2 Phase 3 – Individual Teaching Interviews.....	53
5.2.1 General features .....	53
5.2.2 Demographics of the Phase 3 Participants.....	53
5.3 Phase 4 – Group Teaching Interviews .....	54
5.3.1 General features .....	54
5.3.2 Demographics of the Phase 4 participants .....	54
5.4 The Interview Description – Phases 3 and 4.....	55

5.4.1 Clinical Part .....	55
5.4.2 Teaching Part .....	55
5.5 The Interview with hands on activity and simulation - Phase 5 .....	59
5.5.1 General Features .....	59
5.5.2 Demographics of the Phase 5 participants .....	60
CHAPTER 6 Results of Clinical Interviews.....	61
6.1 Chapter Overview .....	61
6.2 Interview Analysis Procedure.....	61
6.2.1 Credibility .....	62
6.2.2 Triangulation.....	62
6.2.2.1 Member Check.....	63
6.2.2.2. Debriefing .....	63
6.2.3 Dependability .....	63
6.3 Results of the Clinical Interviews.....	64
6.3.1 Familiarity with X-rays and ultrasound pictures, difficulties with the others .....	64
6.3.2 “X-rays and Ultrasound Are Real, The Others Are Virtual” .....	64
6.3.3 Theme 1: From “knowing nothing” about X-rays to “knowing something” .....	65
6.3.4 Theme 2: Focusing on safety while discussing their own experience with X-rays .....	65
6.3.5 The importance of historical perspective .....	66
6.3.6 “X-rays are flow of energy” .....	67
i. Theme 3: “Density Determines Visibility” .....	67
1. “Bones are denser, softer tissues are less dense” .....	68
6.3.7.2 “Density idea is dominant but not strong” .....	69
6.3.7.3 Tendency to explain visibility by local characteristics .....	70
6.3.8 “Ultrasound is able to see softer tissues than X-rays” .....	71
6.3.9 “Ultrasound is less dangerous than X-rays” .....	72
6.3.9.1 How an ultrasound machine works.....	72
6.3.9.2 Other differences between X-rays and ultrasound.....	73
6.3.10 Theme 4: “Transfer of sound properties to ultrasound and light properties to X-rays” .....	74
6.3.10.1 “Sound travels faster in a denser medium” .....	75

6.3.10.2 “Sound from vibration, light from energy” .....	75
6.3.10.3 “Ultrasound cannot propagate through empty space, X-rays can” .....	75
6.3.10.4 “X-rays are much faster than ultrasound” .....	76
6.3.10.5 “Vibrations in ultrasound” .....	76
6.3.10.6 “Sound doesn’t belong to the spectrum” .....	76
6.3.11 Confusion “transverse – longitudinal” .....	77
6.3.12 Theme 5: Not knowing the order for spectrum.....	78
6.3.12.1 Theme 5 (cont.): Frequency, wavelength, energy, strength of X-rays .....	78
6.3.12.2 Theme 5 (cont.): “Ultraviolet is more damaging than X-rays” .....	79
6.3.12.3 Theme 5 (cont. ): X-rays and Gamma-rays parts of the spectrum.....	80
6.3.13 Some other auxiliary discussions and findings .....	81
6.3.13.1 Doppler Effect and ultrasound .....	81
6.3.13.2 Other applications of X-rays .....	82
6.3.13.3 Particle-Wave Duality.....	82
6.3.14 Theme 6: Not knowing much about any other imaging techniques .....	83
6.3.15 From where students transfer? - High School and Other Classes Sources .....	85
6.3.16 From where students transfer - Some other sources of information .....	85
6.3.17 Differences across different groups of students .....	86
6.3.18 Relevance of the medical imaging topics in college physics classrooms .....	86
6.3.19 General Attitude .....	88
CHAPTER 7 Results of Teaching Interview .....	89
7.1 Students understanding of CAT scans really improves as the result of completion of the activities .....	89
7.2 Persistence of the Light Attenuation Linearity Idea .....	92
7.3 “Like a puzzle” .....	94
7.3 Results of Group Teaching Interviews – Phase 4 .....	94
7.4 Results of Group Teaching Interviews with Computer Simulation – .....	98
Phase 5 .....	98
7.5 Effect of Group Size on Learning .....	99
7.6 General Students’ Attitude toward The Activities.....	99
7.6.1 Successes.....	99



7.6.2 Problems .....	100
CHAPTER 8 Conclusions and Implications.....	101
8.1 Answering The Research Questions.....	101
8.2 This work in a context of physics education research and physics teaching.....	105
8.3 Recommendations and propositions for further research .....	105
References.....	107
Appendix A.....	116
Appendix B .....	118
First Interview Protocol .....	118
Appendix C .....	119
Interview Protocol - Phases 2-3 .....	119
Appendix D.....	120
Preliminary discussion (clinical interview part) .....	120
Pre-Activity Assessment Discussion .....	120
Main lab (teaching interview part).....	120
Post-Activity Assessment Discussion.....	124
Appendix E .....	125
Preliminary discussion (clinical interview part) .....	125
Pre-Activity Assessment Discussion .....	125
Main lab (teaching interview part).....	125
Post-Activity Assessment Discussion.....	129
Appendix F.....	130
Post-Lab Questionnaire for Phases 3-4.....	130
Post-Lab Questionnaire for Phase 5.....	130

## List of Figures

Figure 1: Pictures used in Clinical Interviews .....	50
Figure 2: The setup presented to students at the beginning of the teaching part of the interview	56
Figure 3: The light source (a light emitting diode) and the light reader (a Pasco™ PASPORT Xplorer universal meter) given to students after the beginning of the teaching part of the interview .....	57
Figure 4: Going around the box with the light source and the light reader .....	58
Figure 5: Determining how the light readings depend on the number of bricks through which the light passes .....	58
Figure 6: Presenting the second box which students are free to open any time .....	59
Figure 7: The box is finally opened at the end of the hands-on activity.....	59
Figure 8: One of the spectrum picture given by an interviewed student .....	78
Figure 9: A typical LEGO™ configuration predicted by a student according to light measurements across the closed box.....	92
Figure 10: A typical “exponential” graph made by a student after the “linear” prediction.....	94

## **List of Tables**

<b>Table 1 Five Research Traditions in Qualitative Research according to Creswell [1997]...</b>	<b>32</b>
<b>Table 2 Continuum of Interviews with Increasing Amount Of Structure .....</b>	<b>37</b>

## Preface

This dissertation work (except for a small last part, related to a computer simulation) is an extended comprehensive account of the results that were previously reported in the following peer-reviewed publications:

“Investigating Students' Ideas About X-rays While Developing Teaching Materials for a Medical Physics Course”, Spartak Kalita and Dean Zollman, 2006 Physics Education Research Conference Proceedings, July 26-27, Syracuse, NY

“Investigating Students' Ideas About X-rays While Developing Teaching Materials for a Medical Physics Course”, Spartak Kalita and Dean Zollman, Proceedings of 2007 National Association for Research in Science Teaching Annual Meeting, April 15-18, New Orleans, LA

“Group Interaction in hands-on activities related to medical image reconstruction”  
Spartak Kalita and Dean Zollman, Proceedings of 2008 National Association for Research in Science Teaching Annual Meeting, March 30 – April 2, Baltimore, MD

and (partially):

“Transfer of Students' Learning: Physics to Medical Imaging” Dean Zollman, Bijaya Aryal and Spartak Kalita, Proceedings of the International Conference on Physics Education: Physics for All, August 13-18, 2006, Tokyo, Japan

Also the results of the work were presented on the following AAPT meetings:

“Students' Models of X-rays & Interactions”, Spartak Kalita and Dean Zollman, Contributed Talk, Fall Meeting of the A-O-K Section of the AAPT, October 8-9, 2004, Little Rock, AK

“Investigating Students' Ideas About X-rays as the Preliminary Stage of the Development of Teaching Materials for a Medical Physics Course”, Spartak Kalita, Dean Zollman and Peter Fletcher, Contributed Talk, Fall Meeting of the A-O-K Section of the AAPT, October 7-8, 2005, Oklahoma City, OK

“Investigating Students' Ideas About X-Rays While Developing Innovative Teaching Materials”, Spartak Kalita and Dean Zollman, Contributed Talk, AAPT Summer National Meeting, July 22-26, 2006 Syracuse, NY

“Using Optical Analogies While Teaching the Physics of X-rays and CAT Scans”, Spartak Kalita and Dean Zollman 2006 Contributed Talk, Fall Meeting of the A-O-K Section of the AAPT, October 27-28, 2006, Emporia, KS

“Transfer of Learning in Medical Imaging: Analogies and Computer Simulations”, Spartak Kalita and Dean Zollman, Contributed Talk, 2007 AAPT Summer National Meeting, July 28-August 1, 2007, Greensboro, NC

“Using Optical Analogies and Computer Simulation While Teaching Physics of CAT-Scans”, Spartak Kalita and Dean Zollman, A-O-K Section Meeting of the AAPT, October 20-21, 2007, Conway, AR

and also (partially):

“Teaching About the Physics of Medical Imaging”, Dean Zollman, Bijaya Aryal, Spartak Kalita and Dyan McBride, AAPT Summer Meeting, July 19-23, 2008, Edmonton, Canada

# CHAPTER 1 Motivation and Goals

## 1.1 Physics Education for Pre-Med Students

Physics education research has gone a long way in recent decades and has made a great contribution, becoming the integral and indispensable part of research in many departments. Unfortunately this success for various reasons has not been shared equally among different topics and curriculums; particularly not enough has been done to address the needs of pre-med students' population.

At the same time contemporary medicine involves much more fundamental physics than it previously did. Although the topics directly related to medical procedures – both diagnostic and treatment – do appear in the majority of algebra-based physics textbooks but these concepts are often considered not important for the main development of the course and very often neglected and even skipped by physics instructors. Sometimes these sections are clearly subtitled as optional, and almost always have no homework problems associated with them [Halliday, Resnick, Walker, 2005], [Giancoli, 2005].

Non-physics (and especially non-science) students often complain that physics classes lack relevance and take them rather unwillingly, just because these courses are required. This problem is probably severest among pre-med students, for whom a high competitiveness and urgent necessity to get a good grade increases the challenge.

This situation is not only unfortunate; it is somewhat strange and illogical. Modern physics gives teachers a lot of possibilities to demonstrate how well connected to medicine it might be – even starting with the very basic mechanics [Christensen, 2001], not talking about physics aspects of various medical procedures which are numerous, sophisticated, extremely important and diverse.

This also can be put in a context of a larger global effort of shifting control over the physics curriculum from the rather “private” interests of scientists to the public interest (in our case – interests of medical communities and of course - all of us, their patients) [Black, 2001; Euler 2000] and of preparation for the lifetime of fast technological and social change that the upcoming generation expects to face [Goodstein, 1999; Redish 2000]

## 1.2 Modern Miracle Medical Machines Project

Some of the above mentioned issues were addressed in medical courses around the country designed and implemented in recent years [Amador, 1994, Christensen, 2001] but a more systematic effort looks very urgent here. For this purpose the Modern Miracle Medical Machine (which is called MMMM in the further text) project has been undertaken. Its declared goals are the following:

- *conduct research on the reasoning and models that students use as they transfer basic physics knowledge in the application of physics to contemporary medicine,*
- *develop active engagement teaching-learning materials to help students learn about the applications of 20th and 21st Century physics to contemporary medical diagnosis and procedures, and*
- *work toward a change in the culture of teaching introductory physics so that contemporary physics and contemporary medical applications are integrated throughout the algebra-based physics course, rather than being placed in secondary (optional) roles or at the end where it is never discussed thoroughly [MMMM grant proposal]*

This thesis work is done mainly under the framework of this endeavor and the research questions that that are asked and answered below are closely connected to the above goals.

An MMMM class has been taught already at KSU once few years ago [Zollman, 2002] in a limited pilot version – as an advanced undergraduate level physics course for highly motivated and successful pre-med students who found room in their busy schedules for this not-required experimental class and did not fear to jeopardize their precious GPA standings. Before that, the Visual Quantum Mechanics project [1997] was developed here, helping students successfully envisage obscurities of the atomic theory using modern computer technology and later it was extensively used for the purposes of MMMM. A general framework for dynamic transfer of learning was also developed by our KSU Physics Education Research Group [Rebello et al, 2002] which will be implemented for this project as a specific transfer between physics and medicine. Thus, this work is also an integrated part of multi-dimensional, multi-level, long-term enterprise, deeply rooted in our environment and tradition of the Kansas State University Physics Education Research Group (PERG).

Each of the instructional units of the MMMM project is based on one of the diagnostic (or treatment) tools that are available to contemporary physicians and shows how basic physics

principles aid in this diagnosis and treatment. The resulting instructional materials should help students transfer knowledge and understand the connection between medicine and contemporary physics. Additional instructor's materials should facilitate the learning of these materials without the need to modify entirely the existing algebra-based courses (or to read a large quantity of the medical diagnostic or treatment literature).

The main instructional units will be the following ones:

- X-Rays
- Computer Tomography
- Positron Emission Tomography
- Magnetic Resonance Imaging (Classical and Quantum Versions)
- Refractive Eye Surgery with Lasers

### **1.3 X-rays and CAT-scans in MMMM**

The X-ray and CAT-scan learning unit will be a central one in our MMMM set of materials. Students' understanding of X-rays has not been studied previously and thus a study of the nature described here is needed to design appropriate learning materials.

Almost all the students either have undergone some X-ray procedure in their lives or know somebody who has, and they are likely to have some preconceived ideas about how physics is involved in the creation of X-ray images. Even if they are not quite familiar with X-rays, they are likely to be inclined to build such models right on the spot when asked to do so. Here we are in a more fortunate position than for instance in the case of PET or MRI where students know these techniques only by their names. But also our task is more challenging since we have to take into account these ideas when building our instructional materials.

### **1.4 Research Purposes and Questions**

Our research questions are naturally connected to the goals of MMMM. The first three may be associated with the first goal and the last one can be connected to the second. So these research questions are:

- From which sources do students transfer their learning about X-rays?
- How do they elicit and construct their models of X-rays?
- Which factors affect their dynamic model construction and facilitate transfer during the interview?
- Are the proposed activities pedagogically effective?

Also during the later phases of this research effort we came up with one more research question, the answer to which can be added to the mainstream results of our work:

- How group and individual students' learning behavior are compared in our settings?

### **1.5 Broader Impact**

Apart from answering the above formulated research questions this investigation will also provide insights into how students' interaction with an interviewer-instructor and with peers, with hands-on materials and with computer simulations helps them to construct mental models of physics phenomena and transfer learning from various sources while working on the topics that are directly related to their (pre-)professional interests.

### **1.6 Roadmap of This Dissertation**

In Chapter 2 (Predecessors and Context) we will provide a comprehensive summary of relevant research literature as well as a review of the history of X-rays and medical imaging. In Chapter 3 (Methodology) we describe the various aspects of qualitative research, phenomenological philosophy, clinical and teaching interview methodology. In Chapter 4 (Clinical Interviews) and Chapter 5 (Teaching Interviews) we describe the research design based on the theoretical framework, the research setting, as well as data collection and analysis methods. In Chapters 6 (Results of Clinical Interviews) and Chapter 7 (Results of Teaching Interviews) we will present the key findings of our study. In Chapter 8 (Summary and Implications) we will discuss the overall results of the study, how do they respond to our research questions. Recommendations for instructors and curriculum developers are also included in this chapter.



## CHAPTER 2 Predecessors and Context

### 2.1 Chapter Overview

The literature and history synopsis in this chapter is presented in five sections: on constructivism, on transfer of learning, on knowledge structures and mental models, on history of X-rays and history of medical imaging in general.

### 2.2 Constructivist Approach

One of the most central aspects of this study is that we adopt here a constructivist approach. Constructivism in general is a very broad theme that spreads over the subjects of biology, history, linguistics, neuroscience, medicine, philosophy, physics, political science and others. Partially because of all these multiple meanings and connotations the word “constructivism” has been overused recently and even became an annoying omnipresent claptrap, so an elaborate clarification is needed.

In a narrow educational sense, it may be squeezed down to the view that “*the learning is a constructive process in which the learner is building an internal illustration of knowledge, a personal interpretation of experience*” [Bednar, Cunnigham, Duffy, Perry, 1995]. Mahoney [1988] notes: “*Constructivism refers to a family of theories that share the assertion that human knowledge and experience entail the (pro)active participation of the individual*” Practically, in other words, it means that constructivists give up realistic views of epistemology and recognize that there is no such thing as knowledge “out there” independent of the knower, but only knowledge we construct for ourselves as we learn. The simplistic objectivistic assumption that the knowledge is “true” if it corresponds to reality and “false” otherwise is given up here.

But, by no way is constructivism another epistemology or a way of knowing (what critics often forget). This is rather another way of thinking about knowing in general. Bodner et al [2000] attribute the following systematized features to constructivist theories of learning:

Knowledge:

1. is created in the learner's mind,
2. is seldom transferred intact from teacher to learner,
3. is created, must be functional within the context in which it is created, and
4. is not evaluated in terms of scientific correctness, but rather in terms of its usefulness.

The modern constructivist movement has grown basically from frustration with traditional educational techniques in academia where rote, ineffective memorization, regurgitation of facts and the outdated partition of knowledge into completely different subjects led to a situation where students were not necessarily able to transfer what they have learned and to apply it in real life [Dixon-Kraus 1996]. Alfred North Whitehead [1929] once argued that the way students learn things in school produces “inert” knowledge - knowledge that can be used to answer items on a class test but which is not really retrievable by the student when she or he is trying to solve an actual problem that requires that knowledge [Flavell and Piaget 1963]. Another problem was that the established rationalist and behaviorist instructional practices were focused on covering an extensive subject area, reducing the amount of time for problem-solving and thinking beyond the facts about which they had been informed, minimizing independent and autonomous learning. It encouraged didactic lecture formats rather than active student learning [Holt and Willard-Holt 2000]. And the logical reaction to this disappointment was the viewpoint that instructors should only offer proper learning situations that will allow students to develop their own knowledge, meaning and truth that will be useful in later life. Providing a problem-solving context for actively engaging students in the thoughtful application of knowledge is an important variable in increasing learning [McMahon 1997].

Constructivist tradition in human thinking goes back to ancient philosophers although in these early stages it is hardly separable from other issues they wrote about. The pristine forms of constructivism can be traced back to ancient times, particularly in European philosophical tradition to such Greek thinkers as Heraclites (“Everything flows, nothing stands still”) and Protagoras (“Man is the measure of all things”)

Historian Giambattista Vico (1668-1744) emphasized the role of fantasy and myth in

human adaptation. He stated (1708) that “the norm of the truth is to have made it”. His so-called “verum factum” principle [De Italorum Sapiencia 1710] stated that truth is verified through creation or invention and not, as Descartes had alleged, through observation and reflection. “*The criterion and rule of the true is to have made it. Accordingly, our clear and distinct idea of the mind cannot be a criterion of the mind itself, still less of other truths. For while the mind perceives itself, it does not make itself.*” By the way, this criterion for truth would later outline the history of civilizations in Vico’s most famous work, the *Scienza Nuova* [The New Science, 1725], where he claimed that our whole communal life – like mathematics – is utterly constructed.

Ernst von Glasersfeld called Vico “the first true constructivist” [An Introduction to Radical Constructivism, 1984].

Immanuel Kant (1724-1804) pointed out the power of patterns in our thinking, and considered ideas as regulative principles in our experiencing. He also stated that knowledge could neither be solely reliant on environment or our intrinsic qualities, but on an interaction between the two. His “categories” are clear predecessors of what we now call “constructs” and “schema.”

Jean-Jacques Rousseau strongly influenced modern educational theory through his book “*Emile Or, On Education*” [1762]. But it is very important to point out that his views started rather maturationist tradition in education, and we should distinguish between both, (constructivist and maturationist). DeVries et al. [2002] put this difference in the following words that “*Constructivism is based on the idea that the dialectic or interactionist process of development and learning through the student's active construction should be facilitated and promoted by adults... while the romantic maturationist stream is based on the idea that the student's naturally occurring development should be allowed to flower without adult interventions in a permissive environment*”. This statement clarifies what constructivism is not.

Later Hans Vaihinger, elaborating on Kant’s ideas, stated that the primary purpose of mind and mental processes is not to portray or mirror reality, but to serve individuals in their navigations through life circumstances [The Philosophy of “As If,” 1876]. Vaihinger’s work immensely influenced the works of William James, the father of modern pragmatist philosophy,

and also George Kelly with his theory of personal constructs [1955]. The core ideas of modern constructivism were most clearly enunciated by John Dewey: *“Only by wrestling with the conditions of the problem at hand, seeking and finding his own solution (not in isolation but in correspondence with the teacher and other pupils) does one learn.”* [How We Think, 1910]. James and Dewey strongly attacked the traditional “spectator theory of knowledge”; being one of the most important philosophers of recent centuries, Dewey even openly defines the whole subject of philosophy as a theory of education [Democracy and Education]. This confession also put a lot of weight to his admirably consistent from top to bottom constructivist views.

Gaston Bachelard, the inventor of “physics psychoanalysis” introduced the concept of “epistemologic obstacle”. Reflecting on the change of scientific paradigm between classical and relativistic mechanics he gave another, “teleological”, perspective to constructivism: *“The meditation on the object takes the form of the project”*. A question always comes first when we search a theory, problems do not come up by themselves, *“All scientific knowledge is in response to a question. If there no were question, there would be no scientific knowledge. Nothing proceeds from itself. Nothing is given. All is constructed.”* [Bachelard, 1934].

Formalization of the constructivism theory was done mainly by Jean Piaget (1896-1980), who is considered *“the great pioneer of the constructivist theory of knowing”* [Glaserfeld, 1990] and *“the most prolific constructivist in our century”* [Glaserfeld, 1996]. Following on the dynamic view of learning proposed by Johann Herbart (1776-1841), Piaget developed a model of cognitive development in which balance was central. Piaget described knowing as a pursuit for a dynamic balance between what is familiar and what is novel. He believed that the fundamental basis of learning was discovery: *“To understand is to discover, to reconstruct by rediscovery, and such conditions must be complied with if in the future individuals are to be formed who are capable of production and creativity and not simply repetition.”* He noted that we organize our worlds by organizing ourselves. *“The formal obligation of transcending endlessly the systems already constructed in order to assure non-contradiction is convergent with the genetic tendency of surpassing, endlessly, the constructions already finished in order to fulfill lacunas”* [Études d’epistemologie génétique, 1972]. The constructivism proposed by Piaget is usually called a genetic or cognitive constructivism, since for him the cognitive function is the same in any human being and is characterized by the cognitive activities of assimilation and accommodation which make the cognitive adaptation of the objects [cognitive obstacles]. *“The focus of Piaget’s*

*theory is the various reconstructions that an individual's thinking goes through in the development of logical reasoning"* [Green & Gredler, 2002].

Piaget articulated mechanisms by which knowledge is internalized by learners. He proposed that through processes of 1) accommodation and 2) assimilation, an individual constructs new knowledge from her or his experiences.

1) Assimilation occurs when people's experiences are aligned with their internal representation of the world. They assimilate their new experience into an already existing framework. Accommodation is the process of reframing one's mental representation of the external world to fit new experiences.

2) Accommodation occurs when the world operation contradicts our expectations. By accommodating this new experience and reconsidering our model of the way the world works, we learn from the experience of failure.

By the way, Jean Piaget strongly disagrees with traditional views and sees play as an important and necessary part of the student's cognitive development and has provided scientific evidence for his views. Constructivism no longer considers games as aimless and of little importance.

Similarly, Kelly [1955] uses the metaphor of "man-the-scientist". He supposes that everyday people in the course of their everyday lives act like scientists. Thus each person builds for him or herself a model of the world which is constantly being tested and modified until a coherent construct system is created that not only explains but "anticipates" events.

Ludwig Fleck [1929] revived the old ideas of Vico about the role of fantasy in human thinking "*The content of our knowledge must be considered the free creation of our culture. It resembles a traditional myth*". He characterized learning itself especially the initial stage of professional education as "gentle duress of apprenticeship" [1935]. From combining his and similar ideas with those of Piaget, so called Radical Constructivism, where learning was considered a very individualistic process, was later developed: "*Knowledge, no matter how it be defined, is in the heads of the persons, and that the thinking subject has no alternative but to construct what he or she knows on the basis of his or her experience. What we make of experience constitutes the only world we consciously live in*" [Glaserfeld, 1995]. "*To be 'radical' here "means to accept the subjective character not only of emotions, of pleasure and*

*pain, but also of the perceived world and the knowledge about it without evasions and tricks.”*  
[Schwegler, 2001]

But, approximately at the same time as Piaget and Fleck, Lev Vygotsky made a strong argument for the need for students to demonstrate their knowledge by creating explanations and interpreting their work for others. [1978] He insisted that it was not possible to separate learning from its social context, emphasized the role of language and culture in cognitive development. He directly claimed that former cognitivists had failed to understand that learning is collaborative. Vygotsky distinguishes between two developmental levels. The level of actual development is the level that the learner has already reached, and consequently where she or he is capable of solving problems independently. The level of potential development (separated from the level of actual development by the so called "zone of proximal development") is the level of development that the learner is capable of reaching under the guidance of teachers (or in collaboration with peers).

It somewhat differs from the fixed “biological” nature of stages of development, proposed by Piaget, but complements rather than contradicts his theoretical outline. Learners are challenged within, yet slightly above their current level of development. Through a process of “scaffolding” a student can be extended beyond the limitations of physical maturation to the extent that the development process lags behind the learning process. [Vygotsky, 1978]

Postpositivist philosophers Kuhn [1970] and Feyerabend [1988] developed the ideas of Fleck in a more Vygotskian direction, they emphasized that science is a communal enterprise rather than an individual effort of educators. Social Constructivists [Solomon. 1987] pointed out the role of social interactions which greatly influence the way in which learners construct their schema. Gergen *et al.* [1992] emphasized the crucial function of language and went farther in the social direction, insisting that knowledge does not reside in individuals but rather within social groups. His ideas go back to the latter writings of Wittgenstein [1953] whose concept of language-games is very similar to language-supported consensual domains used by some constructivists. Glasersfeld [1995], following his above outlined paradigm, criticized these views for overplaying social factors and neglecting cognitive psychology.

The theme of developmental self-organization pervades constructive views of human experience. Bruner [1966] states that a constructivist theory of instruction should address four major aspects:

1. *Predisposition towards learning*
2. *The ways in which a body of knowledge can be structured so that it can be most readily grasped by the learner*
3. *The most effective sequences in which to present material*
4. *The nature and pacing of rewards and punishments. Good methods for structuring knowledge should result in simplifying, generating new propositions, and increasing the manipulation of information*

Also he proposed a few main teaching principles [around 1973]:

1. *Instruction must be concerned with the experiences and contexts that make the student willing and able to learn (readiness).*
2. *Instruction must be structured so that it can be easily grasped by the student (spiral organization).*
3. *Instruction should be designed to facilitate extrapolation and or fill in the gaps (going beyond the information given).*

In his more recent work, Bruner [1986, 1990] also has expanded his theoretical framework based primarily on Piaget to encompass also the social and cultural aspects of learning. Jonassen [1994] proposed the eight following characteristics that differentiate constructivist learning environments:

1. *Constructivist learning environments provide multiple representations of reality.*
2. *Multiple representations avoid oversimplification and represent the complexity of the real world.*
3. *Constructivist learning environments emphasize knowledge construction instead of knowledge reproduction.*
4. *Constructivist learning environments emphasize authentic tasks in a meaningful context rather than abstract instruction out of context.*
5. *Constructivist learning environments provide learning environments such as real-world settings or case-based learning instead of predetermined sequences of instruction.*
6. *Constructivist learning environments encourage thoughtful reflection on experience.*
7. *Constructivist learning environments “enable context- and content- dependent knowledge construction.”*

8. *Constructivist learning environments support “collaborative construction of knowledge through social negotiation, not competition among learners for recognition.”*

Driver [1988] lists six features of a constructivist perspective in schooling:

1. *Learners are not viewed as passive but are seen as purposive and ultimately responsible for their own learning; they bring their prior conceptions to learning situations;*
2. *Learning is considered to involve an active process on the part of the learner; it involves the construction of meaning and often takes place through inter-personal negotiation*
3. *Knowledge is not ‘out there’ but is personally and socially constructed, its status is problematic. It may be evaluated by the individual in terms of the extent to which it fits with their experience and is coherent with other aspects of their knowledge;*
4. *Teachers also bring their prior conceptions to learning situations not only in terms of their subject knowledge but also their views of teaching and learning. These can influence their ways of interacting in the classroom;*
5. *Teaching is not the transmission of knowledge but involves the organization of the situations in the classroom and the design of tasks in a way which promotes scientific learning;*
6. *The curriculum is not that which is to be learned, but a program of learning tasks, materials, and resources from which students construct their knowledge.*

In their book “A Case for Constructivist Classrooms”, J.G. and M.G. Brooks state 12 principals essential to constructivist teaching:

1. *Encouragement and acceptance of student autonomy and initiative.*
2. *Utilization of raw data and primary sources along with manipulative, interactive, and physical materials.*
3. *When planning, teachers use cognitive terminology such as “classify”, “analyze”, and “create.”*
4. *Allowance of student responses to drive lessons, shift instructional strategies, and alter content.*
5. *Inquiry concerning students’ understanding of concept before sharing their own understanding of those concepts.*
6. *Encouragement of students to engage in dialogue, both with the teacher and with one another.*



7. *Encouragement of student inquiry by asking thoughtful, open-ended questions and encouraging students to ask questions of each other.*
8. *Pursuit of elaboration of students' initial responses.*
9. *Engagement of students in experiences that might engender contradictions to their initial hypotheses and then encourage discussion.*
10. *Allowances for wait time after posing questions.*
11. *Providing time for students to construct relationships and create metaphors.*
12. *Nurturing students' natural curiosity through frequent use of the learning cycle mode*

Philips [1995] extended and generalized the binary Piaget-Vygotsky view of constructivism by putting all the possible complexities of the approach into the space formed by three different axes.

1. *"individual psychology versus public discipline."*
2. *"humans the creators versus nature the instructor"*
3. *"knower is actor or doer vs. knower is observer or spectator"*

Although this classification looks dubious in general and the second dimension is hardly distinguishable from the third one when we discuss real examples, it is difficult to disagree with Philips that the second dimension is the most crucial because it contains a point along its axis where a person ceases to be a constructivist.

Criticism of the constructivist approach is also abundant. Constructivism is often misinterpreted in a classroom situation, and people may think that it means that a learning environment is largely or even completely controlled by students. Schwartz & Bransford [1998] respond to this objection that constructivism has little to do with who controls the environment, rather it refers to the belief that knowledge is constructed in a student's head regardless of the environment and even students in a lecture construct their own knowledge not only during their hands-on collective or individual tasks.

Bodner [2001] systematized various accusations against constructivism in the three following groups:

1. too relativistic (some may think that it questions whether a real world even exists)
2. too permissive (teachers aren't encouraged to tell students when they are wrong):
3. too process-oriented (concentrates on the process of learning and ignores the role of those who influence the learning):

Bodner responds to these doubts and objections that the majority of them should be directed only to Piagetian tradition of cognitive constructivism. Especially it refers to Radical Constructivism, which is somewhat overemphasizes the role of the individual in knowledge. Vygotskian tradition of social constructivism, that highlights interaction between learners, is a primary mechanism through which the learning occurs is much less vulnerable to these attacks – at least the second and the third of aforementioned problematic points are no longer actual here. The first one is more intricate and a subject of eternal philosophical debate. For practical purposes we must stay far both from naïve realism and naïve solipsism here.

## **2.2 Transfer of Learning**

Transfer of learning is defined as applying what has been learned in one situation to a different situation [Singley & Anderson, 1989, Reed 1993] and sometimes is reasonably considered as the ultimate goal of the whole educational process [McKeough, Lupart & Marini, 1995] Applying this statement to our research, we are going to study the transfer of students' physics knowledge, acquired primarily in their high school and college classes, to the subject of medicine with it's applications.

For the main part of the XX century the research on transfer of learning has focused on whether students who had learned how to solve a particular problem in a specific situation can apply the same strategy to similar problems in other contexts. This approach dates back to the first behaviorist psychologists Thorndike & Woodworth[1901] Among the typical examples there are the “fortress vs. tumor” problem [Duncker, 1945; Gick and Holyoak, 1980] and the “jealous spouses vs. cannibal-missionary” problem [Reed et al., 1974]. These and other investigators, with all their scientific expertise (and perhaps biases!) observe deep structural resemblance between the two problems in each pair - and they believed that students could emulate the same thinking, and through analogical transfer would be able after solving the first problem, to successfully solve the second one. Yet, the results were not quite encouraging and showed that transfer, measured this way, is quite rare.

The apparent problem was that the underlying concept in every problem was pre-defined (even unconsciously), and this specific evidence of transfer was looked for. But intuitively we know from our everyday experience that we don't have to invent a new procedure each time we are faced with a new situation. At least something always transfers from one situation to another.

So the researchers just might be overly focused on what should be transferred by students and miss what students actually transfer.

Previous researchers might describe transfer as involving recognizing similarity of surface features [Thorndike, 1906] or deep structure [Judd, 1908] between the two contexts. Others assumed that transfer engages constructing symbolic mental representation (schemas) in the learning context and then mapping and applying those schemas to a particular transfer context [Anderson & Thompson, 1989; Gentner, 1983; Holyoak & Thagard, 1989]. Greeno *et al.* [1993] and other researchers argued that this process, while possible, is rather rare. Instead, they focus on activities that the learner performs in the learning context. The learner interacts and becomes “attuned to the affordances” of the learning contexts of its “potential states of affairs” and brings the knowledge of these aspects of the learning context into the transfer context.

The emerging view on transfer of learning is different from the traditional one, which was developed in the above mentioned papers, and involves the three following interdependent tendencies: [Rebello *et al.*, 2002]

1. *We try to look at transfer rather from the students’ perspective than a pre-defined researcher’s perspective; we ask what similarities the students see in presented situations (Actors Oriented Model of Transfer) [Lobato, 1996, 2003]*
2. *We describe transfer rather as a dynamic phenomenon – when the learner dynamically constructs knowledge in the target scenario, not merely applies what has been studied previously (shift toward a more constructivist view)*
3. *We go beyond looking at transfer from an individual cognitive viewpoint and include socio-cultural factors in our discussion (shift from Piagetian to Vygotskian perspective within the constructivist paradigm – it will be discussed below) [Greeno, Moore, & Smith, 1993]*

Various efforts were undertaken to resolve that conflicting descriptions of transfer as ubiquitous, from one side and virtually non-existent from another. First of all, the approach where researchers predetermine what should transfer was looked at as too limited. Lobato [1996] emphasized that students may transfer in ways that the researchers may not have previously considered. She defended a student-centered perspective to find out what students do transfer and look into the mediating factors. An understanding of these factors can provide us insights into the kinds of interventions that might facilitate productive transfer. Using the ideas of “perceived

similarities” [Hoeffding, 1892] and “situated cognition” [Lave & Wenger, 1991], Lobato built up her “Actor-Oriented Model of Transfer”. Rather than similarities perceived by the researcher, this model relies on “personal creations of relations of similarity” by the learner, between the initial learning and transfer contexts.

Many socio-cultural aspects of transfer [Greeno et al., 1993] and situated cognition [Lave & Wenger, 1991] were also included into Lobato’s model. Transfer doesn’t take place exclusively in a student’s mind but the external factors such as interactions with peers, teachers, should be included in our consideration, all the elements of the environment are important here.

Another contemporary perspective of transfer was offered by Bransford and Schwartz [1999]. They described traditional transfer studies as focused on “sequestered problem solving” in which a learner had to solve a problem in the transfer context without scaffolding (that was naturally provided in the initial learning context). Bransford and Schwartz upheld the perspective of transfer as “preparation for future learning.” and argued that the undue focus on whether or not students can just problem-solve in the transfer context had led to the lack of evidence for transfer. While transfer is more likely if students are provided with opportunities to reconstruct their learning in the transfer context just as they were in the previous learning context.

Dufresne *et al.* [2002] describe transfer as a “*complex dynamical process leading to the activation and application of knowledge in response to context.*” That includes two sub-processes. First is the “readout filter” noticing relevant information in a particular situation. Second is the “expectation filter” which includes activating and applying the knowledge pieces to make inferences. Then transfer is described as a process through which learners align their readouts and expectations to achieve a state of “quasi-equilibrium”.

Hammer *et al.* [2002] describe transfer as a “manifold ontology” of “locally coherent resources activated or deactivated based on the learner’s epistemic “frame” in the context.

He separates his position from the position of previous researchers, who have used a “unitary ontology” of transfer of an “intact cognitive unit.” These resources depend on each other and there is a high probability that they can be activated together. And transfer occurs when the learner comes in a similar state in a new context and triggers the same set of resources.

Schwartz *et al.* [2002] distinguish between “transferring out of” and “transferring into” situations. The former is the traditional and rarely observed transfer; the latter is the modern view. The first is the conventional (and thus rather rarely observed transfer). The second one is

consistent with the contemporary approach. “Transferring in” is similar to Broudy’s [1977] view of “knowing in”, that means understanding a new situation in light of previous experiences. Interpretive associations are rather subtle and are ignored in traditional assessments such as sequestered problem solving, which concentrate on replicative and applicative associations.

diSessa and Wagner [2002] categorize transfer based on the grain size of the transferred knowledge, frequency of transfer and need for new learning to facilitate transfer.

Redish [2003] gives a picture of a two-level framework based on fundamental cognitive psychological and neurophysiologic theories. The first (lower) level comprises associations between knowledge components, which correspond to “relations of similarity” in Lobato's [1996] Actor-Oriented Model. The second (upper) level contains “executive control” that boosts (turns on) or restrains (turns off) the associations between that knowledge components, depending on a learner’s beliefs, anticipations, epistemologies etc.

We choose the interviews (clinical and teaching) as a setting in which to study transfer. The interview is an extensively used instrument in educational research, naturally consistent with the current perspectives of transfer of learning, since it gives us an opportunity to see how students transfer and construct knowledge dynamically. During an interview students may create associations with what they have previously learned spontaneously, without any special external hints – in this case we talk about spontaneous transfer. But when our primary goal is to design instructional materials we must research how students respond to various attempts, direct or non-direct, to change their ideas. In this case an interviewer would purposefully prompt students to create associations and we talk about scaffolded transfer [Rebello *et al.*, 2002].

### **2.3 Knowledge structures and mental models**

Pieces of students knowledge, or “knowledge structures” (mental structures, modes of reasoning [Wittmann, 2002]), that can be transferred by the above discussed mechanism, may include various classification units, that were developed and utilized by science education researchers. These units may be either simple like “phenomenological primitives” [diSessa 1988], “conceptual resources” [Hammer, 2000], “facets” [Minstrell, 1992] or more complicated like “coordination classes” [diSessa & Sherin, 1998] and “mental models” [Glaserfeld, 1989 Vosniadou, 1994, Driver, 1995]. Below the definition of these terms and some discussion on them are given.

### **2.3.1 P-Prims**

The p-prim (short for “phenomenological primitive”) is a minimal abstraction of everyday phenomena. P-prim don’t need any special justification – something happens “because that’s the way things are” [diSessa, 1993]. Hammer [1996] describes them as “maintaining agency,” “actuating agency” and attributes to them the following axiomatic and pragmatic properties:

1. They are small pieces of knowledge
2. When appropriately organized. they can result in scientific thinking
3. Neither right nor wrong, rather they are correctly or incorrectly activated in particular contexts
4. They can help an instructor identify a germ of knowledge that is correct in students’ thinking and build on it, by influencing when they are activated

Hammer and Elby [2002] describe maintaining agency as “*an element of cognitive structure useful for understanding any continuing effect maintained by a continuing cause, such as a light bulb needing a continuous supply of energy to stay lit*”. They define an actuating agency as “*an element of cognitive structure involved in understanding an effect initiated by a cause, when the effect outlasts the cause, such as the strike of a hammer causing a bell to ring*”]

P-prim will be used by us while describing the students’ ideas related to X-rays and medical imaging, but here, below, we will also provide the description of other knowledge structures from which p-prim should be distinguished from.

### **2.3.2 The conceptual resources**

The conceptual resource is defined as “a unit of mind-code.” [Hammer, 2002] It may be illustrated by the analogy with a computer program – the conceptual resource resembles a subroutine (one or few functions that are put together to perform a single operation). In some cases the conceptual resource may coincide with a p-prim – but in general. Hammer [2000] clarifies that the conceptual resource doesn’t have to be either phenomenological or primitive. (In a sense, it is not necessarily the smallest meaningful unit, but rather, the smallest practical unit of mind processes.)

### ***2.3.3 The Facets***

Hunt and Minstrell [1993] pioneered the concept of facets - individual pieces or constructions of a few pieces of knowledge (or strategies of reasoning) that are triggered when a learner tries to make sense out of a situation. Facets are bigger in grain size than p-prims, but are certainly smaller than co-ordination classes (discussed below). While p-prims are not necessarily connected to a particular situation, facets are p-prims that are activated within a specific context. A very illustrative example indicating the difference between p-prims and facets is given by Redish [2004]. “Closer is stronger” is definitely a p-prim, but when students try to explain seasons on the Earth in terms of its proximity to the Sun (the wrong but physically sensible idea), the p-prim manifests itself as a facet.

### ***2.3.4 The coordination classes***

The coordination class is defined as “systematically connected ways of getting information from the world.” which is characterized by “an accumulation of a complex and broad set of strategies and understandings” [diSessa & Sherin, 1998]. A coordination class is a mixture of both knowledge obtaining strategies and knowledge constructs. Examples of coordination classes are “an object” and “an event” [Wittmann, 2001]. Depending on the particular example, coordination class may or may not be of a smaller grain size than a mental model. A thorough discussion on mental models will follow just afterwards.

### ***2.3.5. The mental models***

*“The term mental model is frequently used today in science education research to describe the way students understand various scientific concepts and ideas”* [Zollman, 1999] Mental models may be loosely described as a more or less coherent self-sufficient and self-explanatory knowledge structure that a student consistently uses, implementing a chosen concept in different contexts. “Loosely” means that not all these characteristics are solid – for instance Redish [1994] states that mental models may contain contradictory elements – but even if a mental model is physically or logically contradictory a student still has to use it with a certain, reasonably high, degree of predictability.

Norman [1983] defined the mental model as the mental representation constructed through interaction with the target system and constantly modified throughout this interaction. He attributed to them the following characteristics:

- a) *Mental models are incomplete.*
- b) *People's abilities to "run" [employ] their models are severely limited.*
- c) *Mental models are unstable over time (due to forgetting and mixing of old and new incoming information).*
- d) *Mental models do not have firm boundaries.*
- e) *Mental models are parsimonious. Users tend to do extra physical actions rather than the mental planning that would allow them to avoid those actions.*
- f) *People often feel uncertain of their own knowledge, even when it is in fact complete and correct*

Redish [1994] developed and extended the Norman's list and defines mental models as having the following properties:

1. *They consist of propositions, images, rules of procedure and statements as to when and how they are to be used.*
2. *They may contain contradictory elements.*
3. *They may be incomplete.*
4. *People may not know how to 'run' [employ] the procedures present in their mental models.*
5. *Elements of a mental model do not have firm boundaries. Similar elements may get confused.*
6. *Mental models tend to minimize expenditure of mental energy. People will often do extra physical activities - sometimes very time consuming and difficult – in order to avoid a little bit of serious thinking...*
7. *Students may hold contradictory elements in their minds without being aware that they contradict.*

According to Johnson-Laird [1983] mental models “*are structural analogues of the world as perceived or conceptualized by individuals.*” Gentner and Stevens [1983] argue that “*mental models are related to human knowledge of the world and of how it works i.e., the way people understand some domain of knowledge.*”

Vosniadou [1994] defines the mental model “*as a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning and which has the special characteristic that it preserves the structure of the thing it is supposed to*



represent". She also uses the term of "synthetic model" combining features of student's initial (everyday) model and wishful (scientific) one.

diSessa [1996] depict mental models as "*frequently instructed knowledge forms that...can be the basis for extended and articulate arguments in the course of developing or displaying explanations or in problem solving*" Later [2002] he added to this definition: "*To my mind, mental models should (1) involve a strong, well developed "substrate" knowledge system, such as spatial reasoning, (2) allow explicit hypothetical reasoning, and (3) involve only a small, well defined class of causal inferences*"

Bao and Redish [2001] describe the mental model as "*a robust and coherent knowledge element or strongly associated set of knowledge elements. A mental model may be simple or complex, correct or incorrect, recalled as a whole or generated spontaneously in response to a situation*"

Brandt [2002] claims that from the constructivist point of view the mental models can be defined as "*internal schemes for understanding that both are the tools with which knowledge is constructed and the foundation upon which knowledge is constructed*"

In our research we will primarily use the definition of Mental Model given by Redish [1994].

Of course, introductory college physics students don't often identify appropriate conditions in which to use their mental models properly [Bao & Redish, 2001]. Different models of a particular concept are activated when students are presented with different situations or different problems.

The way students use mental models in different contexts (i.e. problem situation) defines their mental model state. Taking into account the above mention inconsistencies "*the mental states of the individual students tend to be mixed, especially when they are making a transition from an initial state dominated by a naive incorrect model to an expert state... If a student always uses a particular mental model in a reasonably coherent way in response to a set of expert-equivalent questions we say they are in a pure model state. If the student uses a mixture of distinct mental models in response to the set of questions we say the student is in a mixed model state*" [ibid.]

The concept of mental model will be used extensively in our research effort.

## 2.4 Historical Overview of X-rays

Since the XVII century scientists had studied electrical discharges through various gases. They put the gases at low pressure in glass tubes, and using high voltage discharge machines passed electricity through them. In 1857 Heinrich Geissler invented a pump which made use of the vacuum that occurred above a column of mercury. He used the pump to make tubes which, when electricity was passed through them, glowed with different colors [Kassabian, 1910]. In December 1857 Julius Plucker was using a Geissler's tube when he observed a phosphorescent speck on the glass opposite the cathode and this speck moved when a magnet was brought near the tube. Johan Hittorf, a student of Plucker, in 1869, found that putting a screen in the path of “something” that created the speck gave regular shadows that showed that the unknown substance passed through the tube in straight lines [Hedenus, 2002]. Since that mysterious stuff appeared to originate from a cathode Eugene Goldstein in 1876 called it cathode rays. There were different opinions about what those cathode rays might be; their behavior was inconclusive and contradictory under the existing theories. Heinrich Hertz, the discoverer of electromagnetic radiation, found out that cathode rays could penetrate thin metal “windows” set into the side of the tubes. They emerged from these windows in a “diffuse” state like light passing through opal glass and Hertz decided that they must be a form of radiation similar to light. Many German physicists shared his opinions while William Crookes and British scientists thought that the rays are rather very small particles. Phillip Lenard investigated the behavior of cathode rays in air, and they happened only to travel for a few centimeters (still generating phosphorescent effects). . In 1894 J. J. Thomson approximately measured the speed of cathode rays which appeared to be much slower than that speed of light, and a little bit later he measured their  $e/m$  ratio where  $m$  is the mass of each particle and  $e$  is its electric charge [Dahl, 1997]. These findings could not be attributed to anything like light waves and the particle model eventually took the upper hand. Although the electrons, that actually constituted cathode rays, themselves could not yet be identified.

In 1894 Wilhelm Roentgen also had started to do experiments with vacuum tubes. At first he followed up the work of Lenard and Hertz. To detect cathode rays he used sheets of paper, coated with barium platinocyanide which fluoresced when cathode rays fell on them. To monitor the fluorescence better, he covered the vacuum tube with a black cardboard, which glowed in operation. [Kevles, 1996] During one of his experiments Roentgen saw something totally

unexpected. One of the barium platinocyanide coated sheets of paper that lay about two meters away from the vacuum tube was glowing! But Lenard had already thoroughly studied the cathode rays in air and it was well established that could not go further than a few centimeters. Roentgen decided that he observed something very different - and a new type of ray that came from the vacuum tube and passed through the cardboard cover must make the paper glow. He then investigated through what other substances these unknown rays were also able to pass. During one of these experiments he placed his hand in the path of the rays - and saw the shadow of his bones outlined on the barium platinocyanide coated paper!

Roentgen called his newly discovered entity X-ray (for unknown). He determined that they are produced when the cathode rays strike the glass tube walls, and that other materials, notably metals, radiate X-rays when they are hit by cathode rays. It is worth remembering that the precise nature of cathode rays was not known at the time and that light was thought to be waves in the 'aether', a substance with debated obscure properties, so Roentgen's experiments had not produced any conclusive results. In 1896 Roentgen wrote to Ludwig Zehnder "*I have not the slightest idea of the rays' nature.*" [Schedel, 1996] Although he knew that x-rays were substantially different from cathode rays – they were not deviated by magnetic fields – he also knew that they were somewhat similar to light because of the way they created images on photographic emulsions. But he was unable to demonstrate any of the other already known properties of wave – like diffraction, refraction, reflection or polarization. Interestingly, for the lack of better ideas, he tentatively assumed that X-rays are longitudinal waves in the aether, complementing the transverse waves that were visible light!

Only almost 20 years later, when X-rays were already widely used by physicians over the world, the crystal diffraction experiments firmly established that X-rays are actually very high frequency transverse electromagnetic waves, rather than longitudinal waves.

Roentgen's work not only laid a solid foundation to develop the medical applications of the discovery but also captivated the public's imagination, having made him the first ever international celebrity among pure physicists, a couple of decades before Einstein.

As Wilhelm Wien noted, Roentgen probably was not a brilliant scientist full of innovative ideas, he was rather meticulous (and lucky!) experimentalist, but his discovery happened to be probably the hugest single boost to physics progress.

These two last facts provide more dimensions to our work – historical and social. First, contemporary students, not having well-established scientific models of X-rays, may be in somewhat similar positions that the best scientist a hundred years ago were, who also had to transfer somewhat outdated ideas of the XIX century physics to the modern physics phenomena. Second, X-rays are one of naturally fascinating physics phenomena that still easily catch people’s attention, and students are inclined to discuss them more enthusiastically and probably more creatively than many other college physics topics.

## **2.5 Historical Overview of Medical Imaging**

In the first decade of XX century radiology started as a medical sub-specialty. For the first half-century of radiology, the main method involved creating an image by focusing X-rays through the investigated body part directly onto a single piece of film inside a special frame [Kelves, 1997]. In the earliest days, X-raying required 5-10 minutes of exposure time (Nowadays X-rays images are made in milliseconds and the overall dose used is about a hundred times lower than what was necessary 100 years ago. Also, modern advanced X-ray techniques give much better spatial resolution and contrast detail, allowing the diagnosis of microscopic pathologies that could not be identified with older technology.)

Around 1910 various pharmaceutical contrast media agents were utilized to help visualize blood vessels and various hardly visible organs with more clarity and image contrast.

Then, fluorescent screens were implemented and, using special glasses doctors could see X-ray images in real time (This caused the doctor to stare directly into the x-ray beam, creating unwanted exposure to radiation). In 1946, George Schoenander proposed the film cassette changer, which allowed a series of cassettes to be exposed one after another.

The fluorescent setups became more and more complex with mirror optic systems to minimize patient and radiologist dose as much as possible. But around 1955, the X-ray image intensifier (I.I.) was developed, which allowed the physician to display the X-ray movie using a TV camera and monitor, and the outdated fluorescent systems were largely replaced by the I.I/TV combinations.

In the 1950s so called radionuclide scanning came into play. Nuclear medicine studies proposed the insertion of very low-level radioactive materials into the human body. These

radionuclides are seized by the organs in the body and then send out weak radiation signals that are identified and measured by the gamma camera.

In the 1960s the ideas of sonar vision, extensively developed during the WWII for detecting the moving enemy machines, were finally successfully applied to medical imaging. A transducer, placed against the skin of the patient, produces a stream of inaudible ultrasound waves, which go through the body and bounce bounced off the organs inside. Then this transducer detects sound waves while they echo back from the inner body structures. The ultrasound machine, using image reconstruction software, is able to turn this set of signals into live pictures where at least contours of the organs could be seen. [Kundu, 2004]

In the 1970's digital imaging techniques started to be implemented. After a few not practically viable attempts, Godfrey Hounsfield in 1972 announced his invention of CT (Computer Tomography) scanner, on which he worked since 1967 in Hayes, England at THORN EMI Central Research Laboratories. The word "tomography" is derived from the Greek words "tomos" (slice) and "graphia" (describing). He, at first, used gamma rays (and then X-rays) and a detector attached to a revolving frame connected to a digital computer, to make thorough cross sectional images of objects. The prototype CT scanner built in 1971 took 160 parallel readings through 180 angles, each 1° apart. It needed a few hours to get a single slice and more than a day to reconstruct the data. (Today, the best CT systems can produce a single image in less than a second and reconstruct it virtually instantly.)

Allan McLeod Cormack of Tufts University independently developed a similar method at the University of Cape Town/Groote Schuur Hospital, and he shared a Nobel Prize in medicine with Hounsfield in 1979.

In general, Computed Tomography, also known as Computer Aided Tomography (CAT) or body section roentgenography, is a medical imaging method, employing tomography, where digital geometry processing is used to generate a three-dimensional image of the internals of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation. CT creates a large set of data which can be manipulated, through a process known as windowing, in order to reveal various structures based on their ability to obstruct the x-ray beam. Although historically the images generated were in the axial plane (orthogonal to the long axis of the body – Computer Axial Tomography), contemporary scanners allow this data to be reformatted in various planes.

In addition to healthcare, CT is also used in other areas, like nondestructive materials testing.

CT-scans have numerous advantages over regular X-rays (projection radiography). Among the most important ones are the following:

1. CT completely eliminates the superimposition of images of structures outside the area of interest.
2. Because of the inherent high-contrast resolution of CT, differences between tissues that differ in physical density by less than 1% can be distinguished.
3. Data from a single CT imaging procedure consisting of either multiple contiguous or one helical scan can be viewed as images in the axial, coronal, or sagittal planes, depending on the diagnostic task. This is referred to as multiplanar reformatted imaging.

Unfortunately, CT is still regarded as a moderate to high radiation dose diagnostic technique. Of course, recent technical advances have improved radiation efficiency, but our wish to obtain higher-resolution images slows down the decrease of doses of radiation. [Hart, Wall 2004]

X-ray slice data is produced using an X-ray source that revolves around the scanned object. X-ray sensors are positioned on the opposite side of the circle from the X-ray source. Many data scans are gradually taken as the object is progressively passed through the “gantry” (scaffold). These scans are combined together by the mathematical procedure known as tomographic reconstruction.

Newer machines coupled with faster computer systems and programming routines can process not only individual cross sections but continuously changing cross sections as the scaffold, with the object to be imaged, is slowly and smoothly slides through the X-ray circle. Such apparatuses are called helical or spiral CT machines. Their computer systems put together the data of the moving individual slices to generate three-dimensional volumetric information, viewable from many different perspectives on attached monitors.

Sometimes for CT-scans contrast materials (such as intravenous iodinated substances) are used. This is helpful to emphasize structures such as blood vessels - otherwise it would be difficult to demarcate them from their background. Contrast materials can also help acquire functional, physiological information about tissues.

Pixels in images taken by CT scanning are presented in terms of relative radiodensity. (A pixel is a two dimensional unit based on the matrix size and the field of view.)

### ***2.5.1. Four generations of CT scanners***

The first CT scanners used a pencil-thin beam of X-rays directed at one or two detectors. The images were acquired by a "translate-rotate" method in which the X-ray source and the detector in a fixed relative position move across the patient followed by a rotation of the X-ray source/detector combination (gantry) by one degree. In the EMI-Scanner, a pair of images was acquired in about 4 minutes with the gantry rotating a total of 180 degrees. Three detectors were used (one of these being an X-ray source reference), each detector comprising a sodium iodide scintillator and a photomultiplier tube. Some patients had unpleasant experiences within these early scanners, due to the loud sounds and vibrations from the equipment.

Second generation: This design increased the number of detectors and changed the shape of the radiation beam. The x-ray source changed from the pencil-thin beam to a fan shaped beam. The "translate-rotate" method was still used but there was a significant decrease in scanning time. Rotation was increased from one degree to thirty degrees.

Third generation: CT scanners made a dramatic change in the speed at which images could be obtained. In the third generation a fan shaped beam of X-rays is directed to an array of detectors that are fixed in position relative to the X-ray source. This eliminated the time consuming translation stage allowing scan time to be reduced, initially, to 10 seconds per slice. This advance dramatically improved the practicality of CT. Scan times became short enough to image the lungs or the abdomen; previous generations had been limited to the head, or to limbs. Patients have reported more pleasant experiences with the third and fourth generation CT scanners because of greatly reduced noise and vibration compared to earlier models.

Fourth generation: This design was introduced, roughly simultaneously with 3rd generation, and gave approximately equal performance. Instead of a row of detectors which moved with the X-ray source, 4th generation scanners used a stationary 360 degree ring of detectors. The fan shaped x-ray beam rotated around the patient directed at detectors in a non-fixed relationship.

The conventional X-ray systems also continued to be upgraded and adapted to new digital technology. An intermediate analog-to-digital step called "phosphor plate technology" in

currently available worldwide. These plates catch the X-ray energy and require an intermediate processing step to release the stored information so it can be converted into a digital picture.

The main benefits of digital technology are:

- 1) much lower X-ray doses can be used to achieve the same quality as with film
- 2) digital X-ray images can be much easier manipulated using computers
- 3) digital images are much more portable



## CHAPTER 3 Methodology

### 3.1 Chapter Overview

In this chapter, we will present the methodological aspects of our work in somewhat descending order of generalization – first, we will discuss the qualitative research approach in general, then we will talk about phenomenography and phenomenology as a philosophical approach of doing qualitative research, and finally we will describe the interview technique, in general and both clinical and teaching variants of interviews as methods of collecting the data.

### 3.2 Qualitative Research

Qualitative research originated as one of the two major complementary approaches to research methodology in social sciences. To put it simply, it tries to answer questions like “Why?” and “How?” that are different from “What?”, “Where?”, and “When?” of quantitative research.

Some authors refer to qualitative research as a separate paradigm [Creswell, 1998], but the majority of researchers rather downplay the differences between quantitative and qualitative research and look at both of them as complementary [Krathwohl, 1998], and this view is more consistent with the meaning defined by Kuhn [1970], who described the whole scientific progress in the terms of paradigm shifts.

But still the scientific community has not reached a consensual definition of qualitative research. For instance, Lincoln and Guba [1985] openly avoided such an explanation: “*It is not possible to provide a simple definition... A proper impression can be gleaned only from an overall perspective*”. Denzin and Lincoln [1994] stated that “*the field of qualitative research is far from a unified set of principles promulgated by networked groups of scholars*” and that it is “*defined primarily by a series of essential tensions, contradictions, and hesitations.*”

Although some researchers tried to give such a definition, Strauss and Corbin [1990] called qualitative research “any kind of research that produces findings that are not arrived at by means of statistical procedures or other means of quantifications”. Pauly [1991] saw a qualitative research as a five-step process:

1. finding a topic

2. formulating research question
3. gathering the evidence
4. interpreting the evidence
5. telling the researcher's story

Maykut and Morehouse [1994] explain the differences between qualitative and quantitative approach in the following way:

*1. Qualitative approaches use multiple realities which can only be understood by the intersecting socio-psychological constructions. Quantitative approaches have one reality created from dividing and studying parts of an entity.*

*2. Qualitative approaches have interdependency between the knower and the known. Quantitative approaches believe true objectivity exists because the knower can be studied outside of the known.*

*3. Qualitative approaches have non-numerical values that mediate and shape what is understood. Quantitative approaches believe that non-numerical values can be ignored or otherwise rendered unimportant.*

*4. Qualitative approaches involve multidirectional relationships where events shape each other. Quantitative approaches claim that a preceding event can be said to cause a following event.*

*5. Qualitative approaches have only tentative explanations for one time and one place. Quantitative approaches believe that explanations can be generalized to other times and places.*

*6. Qualitative approaches seek to discover or uncover hypotheses. Quantitative approaches generally seek verification or proof of hypotheses.*

Before the 1970s the term “qualitative research” was somewhat marginalized to some topics of anthropology and sociology, but after that time it started to be used in many other disciplines, and became dominant in education studies too. Despite criticism from the defenders of “real” quantitative scientists, new methods of qualitative research have emerged and addressed the issues with reliability and imprecise techniques of data analysis [Becker, 1996].

The inherent flexibility of qualitative research, allowing data collection methods to be varied as a study proceeds can give us a better understanding of what is really happening [Miles and Huberman, 1994].

For many reasons qualitative research methods are more suitable for our project. The lack of previous research on students' ideas about X-rays and medical imaging naturally directed us toward open-ended questions which could not be easily interpreted quantitatively. Our research questions were also outlined very broadly. We were interested in various perspectives and explanations which students bring to our discussion and did not want to impose any norms. All these considerations will be discussed in later chapters, describing the interview process.

Creswell [1997] makes a distinction among five research traditions in qualitative research. He summarized their differences in Table 1.

Phenomenology was picked among these five traditions, and the description of this type of qualitative research and reasoning for this choice is provided in the following subchapter.

<b>Dimension</b>	<b>Biography</b>	<b>Phenomenology</b>	<b>Grounded Theory</b>	<b>Ethnography</b>	<b>Case Study</b>
<b><i>Focus</i></b>	Exploring the life of an individual	Understanding essence of experiences about a phenomenon	Developing a theory grounded in data from the field	Describing and interpreting a cultural and social group	Developing an in-depth analysis of a single case or multiple cases
<b><i>Discipline origin</i></b>	Anthropology Literature History Psychology Sociology	Philosophy Sociology Psychology	Sociology	Cultural anthropology Sociology	Political science Sociology Evaluation Urban studies Other social sciences
<b><i>Data collection</i></b>	Primarily interviews and documents	Long interviews with up to 10 people	Interviews with 20-30 individuals to “saturate” categories and detail a theory	Primarily observations and interviews with additional artifacts during extended time in the field (6 mo - 1 yr)	Multiple sources: Documents Archival records Interviews Observations Physical artifacts
<b><i>Data analysis</i></b>	Stories Epiphanies Historical content	Statements Meanings Meaning themes General description of the experience	Open coding Axial coding Selective coding Conditional matrix	Description Analysis Interpretation	Description Themes Assertions
<b><i>Narrative form</i></b>	Detailed picture of an individual’s life	Description of the “essence” of the experience	Theory or theoretical model	Description of the behavior of a group or an individual	In-depth study of a “case” or “cases”

**Table 1 Five Research Traditions in Qualitative Research according to Creswell [1997]**

## **3.2 Phenomenology and Phenomenography**

### ***3.2.1. Phenomenology***

Most of qualitative research is based on the philosophy of phenomenology (the main thesis of which is that phenomena should be studied without preconceived notions). Phenomenology has had an impact on theoretical thinking and served as a basis for qualitative research in many areas - from health sciences to psychology and in science education. According to van Manen [1990] phenomenology explains how a person orients to lived experience. This is the main feature that differentiates phenomenological research from other qualitative research approaches, thus it focuses on the subjective experience resulting from the inquiry. Patton [2002] writes that in phenomenological research we look at the meaning, structure, and essence of the lived experience of a given phenomenon for a particular person or a group of people. The goal of the investigator in this case is to understand and describe an event from the point of view of the person experiencing it. As Holloway [1997] emphasizes, phenomenology is not a method itself, researchers who utilize this approach are usually reluctant to explain specific techniques, rather they describe phenomenology as a guiding principle that shapes the way in which they conduct their research.

Creswell [1998] treats phenomenological research as one of five “qualitative traditions” rather than an overarching general term. This approach follows the postpositivist philosophy of Kuhn [1970] about multiple scientific paradigms, and consequently the standpoint of Jacob [1987] who discusses qualitative research as being practiced in several more or less distinct academic traditions.

Bogdan et al [1998] describe this area this way:” The phenomenologist is concerned with understanding human behavior from the actor’s own frame of reference instead of facts or causes of the phenomenon.” In general, qualitative methods produce descriptive data as compared to quantitative, numerical and statistical data and the description is given by the participants of our research themselves.

### ***3.2.2 Phenomenography***

Phenomenology and phenomenography are closely connected in different ways. Phenomenography as a qualitative educational research methodology originated under the guidance of Ference Marton, Swedish educational psychologist, from a series of studies of learning among university students of the University of Goteborg, in the 1970s, exactly at the time when the qualitative research was actively conquering new areas of knowledge. The initial research questions that were proposed were extremely broad and sounded abstract and obscure: “*What does it mean, that some people are better at learning than others?*” and “*Why are some people better at learning than others?*” Of course these questions certainly did not have satisfactory universal answers from the very beginning but Marton and his colleagues wanted in their endeavor to take for granted as little as only possible, while the particularities of specific learning situations could be clarified later.

Learning was looked at under ordinary conditions, and the natural goal was to describe it through the eyes of the students themselves. During individual sessions a student was asked to read a text which was either taken from a schoolbook or just made up so it looked like one. Every participant was notified that after reading the passage she or he was expected to talk about it with the interviewer. And, after finishing their reading, the students were accordingly asked about what they understood the text to have been about. Sometimes particular details were also brought into the discussion. Also, the students were solicited to give as full an account of the studied text as possible. After that, the interview went on further with questions about their experience of the situation, and also they were specifically asked how they had gone about learning the text.

The core principle of phenomenography is that it describes people’s conceptions of the world from their own point of view, the researcher is not supposed to impose his own convictions about how humans might or should think about various topics. Phenomenographers study different ways in which individuals understand experience and interpret social phenomena [Holloway, 1997]. In the end, the phenomenographers categorize the responses of participants, present the results in terms of the similarities and differences in relation to how a phenomenon is perceived by individuals.

Bowden [1995] made a distinction between pure phenomenography and developmental phenomenography. The original works of Marton and his colleagues were called “pure phenomenography” because of their “wide” focus on phenomena faced by students in their everyday life, while a phenomenographic research with a “narrower” focus on learning and teaching was called developmental phenomenography. Here the results of the research can help planning teaching activities and lead students toward a more commanding understanding of the studied phenomenon.

### **3.4 Interview as a Research Tool**

#### ***3.4.1 Interviews In General***

There are many methods of data collection in qualitative research. Among them are observations, analyzing documents and artifacts and some others. But the main and the most active (and interactive) one is interviewing, and it is primarily implemented in this project.

Interviewing is the technique of gathering data from humans by asking them questions and getting them to react verbally [Potter, 1996]

Cannell and Kahn [1968] defined the interview as “a two-person conversation initiated by the interviewer for the specific purpose of obtaining research-relevant information, and focused by him on content specified by research objectives of systematic description, prediction, or explanation.”

So an interview is basically a conversation between two or more people (the interviewer and one or few interviewees) in which questions are asked by the interviewer to obtain information from the interviewees. A research interview may be described as a prepared social interaction between a researcher and a subject who is acknowledged as a useful source of information, where the interviewer sets off and manages the communication to acquire relevant and comparable information.

Interviews have proved to be a valuable instrument to look at the dynamics of transfer of learning and give us ideas about how students apply and reconstruct knowledge that they have got somewhere else as they answer our questions. They recently have become the main method for determining students’ understanding of various physics phenomena [Engelhardt et al, 2003]. Of course, we always should be aware that a researcher’s bias can potentially influence the analysis of our data [Scherr and Wittmann, 2002]. Based on the researcher’s agenda a particular

feature of an interviewee's reply can be neglected, or we may unwittingly and sometimes unconsciously lead the student toward a desired answer. The conjecture that student knowledge stays the same during the course of the interview can also have an effect on the interpretation of interview results. In this case we may overlook situations where people "invent" their answers right on the spot, especially (and naturally!) when answering questions they never have previously thought about.

Redish and Steinberg [1999] emphasized "*We need to listen to the students and find ways to learn what they are thinking... In trying to find out what students' real difficulties are, physics education researchers use a variety of tools... One way is to carefully interview a number of students, letting them describe what they think about a particular situation... The researcher encourages the students to think aloud and to explain their reasoning. The goal isn't to help students come up with the correct answer, but rather to understand their thinking*"

Creswell recommended a long interview. McCracken [1988] depicts the long interview as a method that allows us to "*capture the data needed for penetrating qualitative analysis without participant observation, unobtrusive observation, or prolonged contact.*"

Interviews can be characterized in many ways – they can be casual and in depth [Marshall and Roseman, 1989], they can be ethnographic [Walcott, 1982], life history interview [Denzin, 1970], etc.

Krathwohl [1998] classifies interviews putting them along the "continuum of structure" – unstructured, partially structured, semi-structured, structured, and totally structured (This spectrum is presented on the Table 3.2) For the purposes of our research, semi-structured interviews with a developed and ordered interview guide look like the best option.



Unstructured	Partially Structured	Semi-structured	Structured	Totally Structured
Exploratory, only area of interest is chosen, interviewer “follows her nose” in formulating and ordering questions. Impromptu conversation that occur during observation are of this nature	Area is chosen and questions are formulated but order is up to interviewer. Interviewer may add questions or modify them as deemed appropriate. Questions are open-ended, and responses are recorded nearly verbatim, nearly taped	Questions and orders of presentations are open-ended; interviewer records the essence of each response	Questions, and order are predetermined, and responses are coded by the interviewer as they are given	Questions, order and coding are predetermined, and the respondent is presented with alternatives for each question so that phrasing of responses is structured. Questions are self-coding in that each choice is pre-assigned a code

**Table 2 Continuum of Interviews with Increasing Amount Of Structure**

### ***3.4.2 Clinical Interview***

Clinical interviews have been used at many levels of instruction - from primary school to advanced graduate level. Usually the interview is semi-structured, modeled after Piaget [1929]. This format assumes some pre-planning of the content, tasks, and questions, but allows for follow-up questions.

The goal of the clinical interview is to understand students' current reasoning patterns without attempting to change them – but still of course this knowledge still may change naturally because of the above mentioned dynamic considerations.

The outcomes of the interviews (individual or small groups) then can be transferred to the real learning environment (usually larger groups). They provide instructors with a better understanding of how their students look at specific concepts and what alternative, often unusual and unexpected, explanations these students may be expected to give. Clinical interviews help uncover the ideas that students bring with them from previous experiences to the interview although the interview may not tell us much about how students might respond to particular instructional strategies.

Investigators in our group have been working in recent years on many projects that looked at how students transfer their learning from one context to another. We tried to look at it from very different perspectives. Our approach sometimes was more topic-specific - for instance, we researched students' transfer of Newtonian ideas [Allbaugh, 2003] or energy concepts [Itza-Ortiz, Lawrence and Zollman, 2003] from mechanics to electromagnetism classes. Also we looked at transfer from the classroom to the real-world [Engelhardt, Gray and Rebello, 2004; Engelhardt and Rebello, 2003; Engelhardt, Rebello and Itza-Ortiz, 2003]; transfer from everyday practice into interview settings [Hrepic, 2002; Hrepic, Rebello and Zollman, 2002] and even transfer from one problem to another one within one interview [Gray, 2004].

The clinical interviews will be used extensively in the Phases 1-4 of our research.

### ***3.4.3 Teaching Interview***

David Ausubel [1968] wrote that “*the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.*” Usually, “ascertaining” what a student already knows has been done using Piaget’s clinical interviewing technique [1929]. In the early 1980’s, mathematics education researchers began experimenting with another technique of interviewing which they called the “teaching experiment.” [Steffe, 1983]. The teaching experiment is a variation on the interview technique which brings significant differences from the clinical interview format. It incorporates three components: modeling, teaching episodes, and individual or group interviews. The most important aspect of the teaching experiment is the modeling of the students’ responses into a coherent picture of the students’ progress over an extended period. [Steffe and Thompson, 2000]

One of the main goals aims of teaching experiment (or teaching interview – we will use both terms interchangeably) is to provide a connection between educational research and teaching practice. Cobb and Steffe [1983] emphasized that the interest of a researcher during the teaching experiment is in generating hypotheses on what a student might learn and finding ways and means of fostering learning in a given context.

The overall goal of the teaching interview is not only to find the efficient teaching methods but also to look into the differences in the student learning development and see which factors may affect these developments. Komorek and Duit [2004] pointed out, that teaching interviews can be extremely helpful in structuring and refining teaching materials.

Teaching interviews may be conducted with individual students as well as with groups of students. Individual teaching interviews are conducted to examine the dynamics of students’ knowledge construction as they interact with the scaffolding activities and with the teacher-interviewer. Group teaching interviews include one more variable which is the interaction of students with each other, so here we can also examine the social aspects of students’ knowledge construction. (Thus it is more consistent with Vygotskian thoughts of social constructivism.) As students in groups of two or three work together, we can focus not only on their interaction with the instructional materials, but also so on student-student interactions. Also the group teaching interview gives us a setting which is much closer to a real classroom. Although this scenario is

still quite artificial - in a real classroom we can not attend to a single group of students for the entire period of the lesson.

The teaching interview explores how students might react to specific instructional strategies. It has been used by quite a few physics education researchers, like Katsu *et al.* [1993], Engelhardt *et al.* [2003] Komorek and Duit [2004], who were interested in investigating how student ideas of real-world devices changed with instruction. The teaching interview usually consists of multiple teaching episodes - usually with a group of two or three students.

The teaching interview is a mock instructional unit in which the teacher-researcher influences the knowledge construction process of students by providing them with pedagogically appropriate scaffolding. It gives a rich environment in which we can study the dynamics of students' knowledge building and rebuilding while they work and interact with a learning material, with each other and with us (the teacher-interviewer). Our goal is not necessary to find the most optimal, effective way to teach students – it would be too narrow and unrealistic. Rather, we have to investigate the differences in the trajectories of student learning and study which factors influence these trajectories. The results from the teaching interview can be used both for planning teaching modules for students while helping them learn better a particular phenomenon and for constructing our own model of how students learn.

The researcher (interviewer) at the same time performs the role of a teacher in a mock instructional setting which “macrostructurally” utilizes the learning cycle [Karplus, 1974] and “microstructurally” employs Socratic dialog [Hake, 1987]. Karplus' Learning Cycle is a research-based curriculum with an emphasis on the development of students' reasoning skills. It contains three “subcycles “- exploration, concept introduction and application.

In the exploration phase, students explore the concept under investigation through hands-on activities. In the concept introduction phase, a name is given to the concept and the physical laws which explain the observation in the exploration are introduced. In the concept application phase, students apply the newly learned concept to new situations.

Variations of Karplus' Learning Cycle have been adopted later; one of them is Hestenes' Modeling Cycle [Wells, Hestenes, Swackhamer 1995]. The Modeling Cycle is a refinement of the Learning Cycle. Development of a model here starts with a lab in which students define the system and develop various representations for the phenomenon being studied (like, pendulum motion could serve as a so called paradigm lab for the simple harmonic oscillator model).

Students during the first, model development stage of the modeling cycle, would identify the relevant system (as the earth and pendulum), describe the motion in words, create diagrams to represent the motion, identify variables in order to gather data etc. The teacher's questioning would emphasize key ideas and definitions; tackle misconceptions, if necessary, and give students chance to clarify the model, and to extend the model to new situations. Then the students' model is tested in the last, model deployment stage of the cycle.

In our work we will rather rely on the Karplus Learning Cycle, while keeping in our mind the extension of it proposed by Hestenes and his colleagues.

Along the course of the teaching interview students are repetitively asked probing questions as we try to extract as much of their thinking and reasoning processes as we can. The questions tend to be focused around the tasks or actions that our students are asked to reflect about and consequently explain. Demonstrations, hands-on experiences and predict-explain-observe-explain sequences all can be incorporated in the routine. The teaching interview can provide a useful bridge between clinical research and curriculum development because it uses all these instructional elements.

Teaching interviews involve the teacher/interviewer, and the students under investigation and, sometimes, an observer. The interviews are recorded and analyzed like it is done with clinical interviews, and the students' reasoning is the focus of attention just as in the clinical interview. [Steffe and Thompson, 2000] The results of the analysis are then used to guide the next teaching interviews.

For both curriculum development and the resulting teaching methods evaluation of the teaching experiment gives many advantages over the clinical interviews. First, the teaching episodes let us test new techniques, and we can see which technique gives the learners the most conceptual growth. Second, it more directly imitates the natural classroom environment – especially if done with groups of students, as it usually takes place.

At the same time the teaching interview is also different from action research. The action research is typically carried out in “real”, not “mock” teaching settings with the goal to test instructional module that has already been built up, and follows a pre-decided strategy. While in general the teaching interview should rather pave the way for the development of curriculum. And a semi-structured interview allows the researcher to attempt different instructional inputs that may change students' models. If a student or group of students cannot construct a desired

mental model, we can gradually provide increasingly focused prompts until the students succeed. At the same time, if a student already has a consistent model in a given situation, we can give different situations to “test” the student’s model, deciding its robustness. And if one of the students in the group has a correct and coherent model while another one does not, we may incite a discussion as in peer instruction [Mazur, 1997] and watch the following interaction.

But we should always remember that the teaching interview is not a particular research methodology but rather a family of techniques that stretch out along a wide range between clinical interviews and classroom action research. So many variations of the teaching interviews are possible. From contemporary perspectives, discussed in the previous chapter. It crafts a situation that offers a rich stock of experiences and tools that provide an opportunity for the dynamic “personal constructions of relations of similarities” [Lobato, 1996, 2003] and associations [Redish, 2003] among the tools. It makes the most of the possibilities of students’ attunement to the affordances [Greeno et al., 1993] of these tools. The teaching interview allows the researcher to assess student learning in situ, consistent with transfer as preparation for future learning. [Bransford & Schwartz, 1999] It also gives a lot of possibilities for student-student and student-teacher interactions, allowing the researcher to investigate the socio-cultural dynamics of transfer [Greeno et al., 1993; Lobato, 1996, 2003].

The teaching interview provides a level of scaffolding that is much greater than a clinical interview (which does not use it much since we do not try there to change student’s knowledge). Interactions with other students and hands-on activities offer inputs to the sense-making process of students. Also it is worth mentioning that developmental phenomenography discussed in the first half of the chapter is consistent with the aims of the teaching interview.

The teaching interviews will be actively used in the Phases 3-5 of our research.

## **CHAPTER 4 Clinical Interviews**

### **4.1 Chapter Overview**

In this chapter, we will describe both general research settings of our academic environment and specific settings of our interview process, will tell what kind of students have participated in our study, how our interview protocol questions were developed and how they changed over time as the study progressed

### **4.2 General Research Settings**

A single researcher conducted all of the interviews which were recorded on audio (Phases I & II) and besides this, on video (Phases III, IV and V). Additional notes were also taken. The interviewer transcribed each interview starting from the Phase II, although the discussions that did not pertain to physics in any way were not transcribed. When questions arose during analysis, the interview recordings were consulted directly.

Our study was conducted at Manhattan, KS on the main campus of Kansas State University (KSU). KSU is a land-grant university that enrolls about 20,000 undergraduates and about 5000 graduate students. The students body contains students from all 50 U. S. states and more than 90 foreign countries. The participants of this study were taking one of the following introductory physics courses: Concepts of Physics, General Physics, or Engineering Physics. Below we provide descriptions of the format and breadth of these classes and academic backgrounds of students taking them.

#### ***4.2.1 College-Level Physics Classes Taken By Our Participants***

##### ***4.2.1.1 Concepts of Physics***

Concepts of Physics is a conceptual-based four-credit course that is taken primarily by elementary and early childhood education majors. The majority of these students have not taken physics in their high school years. This course was designed by Zollman [1990] about 25 years ago. It uses the Karplus [1974] Learning Cycle, discussed in the previous chapter, but adapted to a large-enrollment format. In the beginning of each week students go to an Activities Center for

about an hour and carry out a series of exploration activities. There they activate their previous knowledge and get a set of shared experiences. These experiences would be the focus of discussion in class on Wednesday, which corresponds to the Concept Introduction phase of the Learning Cycle. At the end of the week students go back to the Activities Center to complete a series of Application activities which require them to apply the concepts learned in the Concept Introduction phase. The lectures on Friday and Monday focus on the Application activities.

#### ***4.2.1.2 General Physics***

General Physics is an introductory algebra-based physics course, usually taken by students majoring in life sciences including pre-meds, the main focus population of our research and curriculum development (and for which we eventually are going to develop our MMMM teaching modules). Many of the students have taken physics in their high school years. Students here separately enroll in lecture, laboratory and recitation sections. The lecture meets for two hours each week, the laboratory for two hours and the recitation for one hour. The recitation and laboratories run parallel with the lecture.

#### ***4.2.1.3 Engineering Physics***

Engineering Physics is an introductory calculus-based physics course taken by students majoring in various engineering areas or in physics. Again, almost all of the students have taken physics in high school. Students enrolled in the class take two hour per week in a large-enrollment lecture. They also have to attend four hours per week of studio. Each studio class may have up to 40 students. The studio, which is an adaptation of Studio Physics first developed by Wilson [1994] at Rensselaer Polytechnic Institute, is in essence a mixing of recitations and laboratories. In the studio classes the students do hands-on activities and discuss how to solve physics problems.

### ***4.2.2 Choosing the Participants***

We cast a wide net of participants from all of the three courses, mainly focusing on General Physics, which is usually taken by pre-meds. The sampling was limited to those who had volunteered.

We did not make any special attempt to choose a specific sample of students (even a “representative” of any kind) from the classes according to the “convenience” sampling principle



outlined above. In a natural way the selection was based on who volunteered and with whom we were able to schedule a mutually suitable time to get together.

In recruiting volunteers for Phase 1, we contacted the physics course instructors and developed a scheme for motivating students. We either paid them \$10 per hour for an interview or gave them a few extra credit points in the course in which they were enrolled. For the rest of the research we sent out e-mails to random KSU students majoring in health-related specialties, who had already taken their compulsory physics class (usually General Physics) or just used General Physics e-mailing lists. All the students since Phase 2 were paid \$10 for each meeting, either individual or group.

This selection method is called “convenience” sampling [Patton, 1990; Seidman, 1998]. But we can safely say that our research subjects had varied interests and varied performance levels. Both genders were adequately represented. This range of participants was similar to the larger population of the course. Such a sample allows for transferability to other similar populations.

Our interview sessions were recorded on audio (and at later phases – video) with permission from the students. The clinical interviews described in the previous chapter were loosely structured and not very formal in its nature. This more or less conversational style gave us the possibility to talk to the interviewees in a more natural and less intimidating way. The freely arranged, relaxed format appeared to make students more willing to speak out what they were thinking at the moment.

### **4.3 Settings of the interviews**

#### ***4.3.1 General interview settings***

We already mentioned that each of the interview sessions were audio recorded and during the later stages –also video recorded. The video recording was indispensable because we also wanted to catch the different modes, either verbal or non-verbal, in which our subjects express their views of a certain aspect of the phenomenon under our investigation. We felt that video recording the interviews would give us the most complete and objective documentation of students’ behavior.

The audio and video recording were set-up in such a way that they were not obtrusive, at least as much as the conditions allowed. The video camera was set up on a tripod (and later –

attached to the wall) that was placed to the side of the interviewees. A small screen television box was hooked up on the video and the subjects were asked to look at it for a moment before every (first) interview, so we could make them aware of what exactly we were capturing during the session. Particularly, to preserve their anonymity we made sure that their faces would not be seen on the screen. At the same time, we made sure that the camera would capture hand gesticulation, graphic depictions and written expressions on the pieces of paper.

#### ***4.3.2 Specific interview settings***

Our interview protocol was developed to guarantee a consistent and pleasant experience for interviewees and the interviewer. A safe, quiet, and convenient location was selected. The interview room had suitable furniture, lighting audio (and then - video) recording equipment. Interviewees were invited to participate in the interview at a time which was convenient to them.

Our study was approved by the Institutional Review Board for research on human subjects prior to all of the interviews. At the beginning of each interview, we discussed with students issues and their possible concerns about confidentiality, our research in general, data gathering procedures, and how data will be used. We clearly explained to the students the conditions of informed consent as required by the KSU Institutional Review Board on Human Subjects. Students were asked to read the informed consent form [Appendix A] and to sign it if they did not object.

We also told that them that they had the right to leave at any time, without any penalty. Then we explicitly reminded our students that this is not like an oral exam of any kind and there were no right or wrong answers to the questions asked. Since the purpose of our interview was to explore their thoughts they were clearly told that it was OK even to “make things up” as they went along. We also told them that in some cases they could be asked follow up questions based on their responses, and that these follow up questions, of course again, did not mean that their answer was unclear or incorrect, but rather it means that we wanted to clarify their reasoning processes.

Usually we spent up to 5 minutes in the beginning of each interview on explaining the aforementioned issues. This part of the talk usually made students more relaxed, and they were able to form a rapport with the interviewer and speak more willingly and freely regarding their thoughts about the phenomenon in focus.

Each interview was brought to an end with a series of reflective questions. Then we thanked each participant of the study for their contribution and provided them with follow-up information if necessary (for the two-interview series).

#### 4.4 Types of questions

As already described above the semi-structured interview format gave us an opportunity to ask the essentially the same questions to each interviewee, but also allowed some flexibility depending on each participants response.

Minichiello, Aroni et al. [“In-Depth Interviewing” 1995] gave the following classification of interview questions:

1. Descriptive Questions: Can be used primarily at the start of each interview or when moving to a new topic. This question type allows interviewees to discuss their experiences in their own words and from their perspective. An example of a descriptive question from this study is, “*Can you describe what you see on this picture?*”

2. Background Demographic Questions: This is somewhat a form of descriptive questions that is used to get the background information of the interviewee. One example of a background question from this research is: “*What physics courses have you taken before?*” This kind of questions is usually reserved for the end of the interview – to avoid “stereotyping” students (unless, of course, interviewees reveal their demographic information themselves – in this case we can proceed with the demographic follow-up questions).

3. Knowledge Questions: Can be used to find out what factual information the interviewee has. The underlying assumption behind this kind of question is that the interviewee knows something about the subject, although it may eventually turn out not to be true. An example of a knowledge question from this study is, “*Can you explain how wavelength and frequency depend on each other?*”

4. Contrasting Questions: Can be used to enable the interviewee to make comparisons of different situations or events and discuss their differences. An example of a contrasting question from this study: “*What are the differences between X-rays and ultrasound?*”

5. Opinion or Value Questions: Can be used to determine what the subject thinks about a specific person or issue. This question type elicits the subject’s opinions and feelings, not just the ‘correct’ answer of some kind and is aimed at gaining access to the cognitive processes of the

interviewee. An example of an opinion questions from this research: “*How did your Physics classes help you in our discussion?*”; “*What might be helpful for future premed Physics students?*”

6. Probing Questions: Can be used to elicit more full information on a particular topic. This question type is used very extensively in this study – it is a natural way to initiate a follow-up discussion about the issues. An example of a probing question from this study is: “*What were you thinking when you tried to answer this question?*”

We extensively used all the mentioned types of questions – both in the standard protocol and in our follow-up discussions.

## **4.5 Research Phases 1 and 2**

### ***4.5.1 Development of the Preliminary Protocol***

At the beginning, we decided to conduct a series of preliminary unstructured one-on-one interviews (with some semi-structured elements modeled after Piaget). In this preliminary study we looked for very general tendencies and did not make a special effort to narrow our attention to the pre-med student population (and for some logistical reasons it wasn’t so easy at that time).

The pilot interview protocol was pilot-tested with a graduate student and then the results were discussed with two other graduate students and with Dr. Zollman. The initial version of the protocol was then revised based on their feedback. This preliminary protocol is included in the Appendix B.

### ***4.5.2 Demographics of the students interviewed during the Phases 1 & 2***

Thus, we looked at students' ideas about X-rays in general and interviewed people with various backgrounds and very different levels of preparation in physics and mathematics. Among the 16 students who were interviewed, 8 were from a conceptual physics class - 4 females studying elementary education and 4 males with non-science majors – and 8 were from a calculus-based physics class - all males with engineering majors (electrical, mechanical or civil engineering). All were in either their sophomore or junior years. For all of them Concepts of Physics or Engineering Physics were the only physics courses that they had taken in college, although all but one of them (an elementary education female) had taken physics in high school.

Half of the students were motivated by extra credit and half were attracted by a small cash payment. Each interview lasted about 30-40 minutes.

During the Phase 2 we interviewed 10 junior and senior pre-medicine or other health-related majors who were concurrently enrolled in General Physics class.

#### ***4.5.3 Designing the interview protocol for the Phase 1***

Looking for the best natural and stress-free way to launch our interview we decided to start our conversation by showing to students a set of eight pictures [Figure 4.1] and then letting the interviewees discuss these images more or less freely. Four of these pictures were X-ray pictures. Three of the X-ray pictures were medical ones - the hand (the first ever X-ray picture of Roentgen's wife's hand), the skull and the chest including the lungs. We assumed that this selection was representative of all medical images that could be recognized by students. One of the X-ray pictures was non-medical - an image of a bag screened by an airport security device, that also should be very familiar to students.

The other four are one each of an ultrasound, MRI and CAT scan and one computer-generated axonometric projection of a human skull. All eight pictures were taken from public domain; they can be easily found on many internet sites by popular search engines like Google.com.

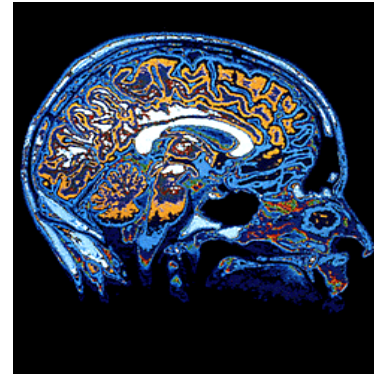
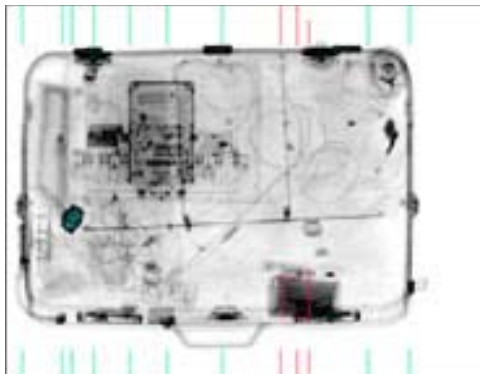
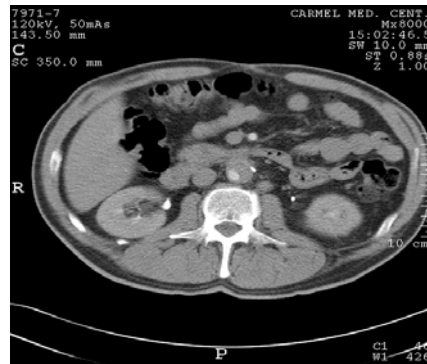


Figure 1: Pictures used in Clinical Interviews

The students were then asked to say something about the images. Our discussion more or less naturally and smoothly went through various physics concepts that students eventually brought up in the conversation - light, waves, particles, the spectrum, etc. Questions like “*Why can we see using X-rays something that cannot be seen with our naked eye?*” “*Why we can see the ring together with the bones but almost cannot see any other tissues including the skin?*” were asked when they either seemed relevant or when students were just stuck and our previous line of discussion had completely died out.

Then the students were asked to compare X-rays to ultrasound and other imaging techniques, prompted to recall some details from their personal experience with X-rays and encouraged to use any information from any other sources that they would find relevant.

This first phase of our research was primarily an exploration to form the basis for a more careful study during the later phases. In this pilot study we did not complete a comprehensive interview analysis, but quite a few interesting themes, which would guide our subsequent research, emerged from it. Some of the information was rather trivial and somewhat expected, but some was quite remarkable. The results of individual studies from the Phases 1-2, later confirmed during the clinical interview parts of the Phases 3-5 will be discussed altogether in Chapter 6.

#### ***4.5.4 Changes in the interview protocol for the Phase 2***

Then we used a more rigid, semi-structured (but otherwise very similar to one that is used in Phase 1) protocol that included a general self-reflective discussion where students were free to express any thoughts about the topic of X-rays and medical imaging, their relevance in the pre-med physics curriculum and on how they should be taught. We also added the question, “*How would you explain X-rays to a 12-year old child?*” giving the students another chance to express their views in more simple and clear if not scientific terms (and double-checking their mental models about the phenomena).

To add more relaxing flavor to our discussion and not to force students even mildly into explanations from the very beginning, in our first question we asked students just to group the pictures in Figure 4.1 (to put them into two or more groups) and then asked why they did it and how different these groups were? The full text of the protocol is included in the Appendix C

From this and subsequent stages a phenomenographic analysis [Marton, 1986] was conducted. We examined the interview transcripts, field notes and student worksheets to find various recurrent categories.



## **CHAPTER 5 Teaching Interviews**

### **5.1 Chapter Overview**

In this chapter, we will describe various characteristics of individual and group teaching interviews that were utilized during the later phases of our study.

### **5.2 Phase 3 – Individual Teaching Interviews**

#### ***5.2.1 General features***

Having accumulated extensive information of what to expect from our targeted pre-med audience, we took into account that the final purpose of our research was the development of teaching materials. We decided to extend the interview process into two stages - one clinical and one teaching interview with each student. The first stage remained basically unchanged from the Phase 2 (since it proved to be comprehensive enough and allowed comparison for reliability purposes). The second stage was a teaching interview. The teaching interview consisted of a fixed protocol (see Appendix D) with scaffolding activities, which depended on students' responses. During this stage we followed a Learning Cycle format to teach students about a few aspects of CAT scanning and the construction of complex medical images. In the teaching interview we provided some information and scaffolding as needed to help the student learn about the topic. In this way we could study how the students rely on their existing knowledge and how they transfer that learning and knowledge to the medical imaging context.

After the interview students were asked to fill a small questionnaire form (Appendix F).

#### ***5.2.2 Demographics of the Phase 3 Participants***

Overall, 5 pre-med students, 5 other health-related majors (who again were enrolled in or have already taken General Physics class) and 2 engineering students (from Engineering Physics class) were interviewed. Also, one student who participated in the Phase 2 this time took part only in the teaching interview (Stage 2).

## **5.3 Phase 4 – Group Teaching Interviews**

### ***5.3.1 General features***

All the previous interviews up to this Phase (Phases 1-3) were conducted with individual students. To investigate group interactions in the transfer process we conducted a series of teaching interviews, each with a few students working as a learning group instead of just one student. We wanted to see whether the different pieces of knowledge that different students bring into our discussion from different sources (being within the Zones of Proximal Developments or ZPD [Vygotsky, 1978] of each other), become more coherent and scientifically consistent with less help (cueing and scaffolding) from an interviewer. Similarly to the previous individual stages our main developmental goals were to help students learn the following target ideas - that CAT-scans are an X-ray-based 3D imaging technique and that CAT-scans are able to produce a more informative full picture, not just a projection because we can move the signal source and the sensor around the research object. And thus the research goal of this study was to look deeply into the peer interaction factor of students' behaviors during the interview process and make implications about further development of the related teaching materials.

### ***5.3.2 Demographics of the Phase 4 participants***

We interviewed 8 groups of students. 4 of them (2 groups of 2 students and 2 groups of 3 students) were enrolled in algebra-based physics class, 4 of them (again 2 groups of 2 students and 2 groups of 3 students) were junior and senior health-related majors who have taken their physics class during previous semesters. Thus, in total 20 people participated in the study. All teaching interviews had duration of approximately 50-60 minutes.

For consistency and comparability purposes we used a protocol as close as possible to that one that we used in our individual learning-teaching interviews.

## **5.4 The Interview Description – Phases 3 and 4**

### ***5.4.1 Clinical Part***

First we conducted the "clinical part" of the interview – although we cannot strictly call them clinical now since we interviewed groups of students. Again we showed to our interviewees pictures related to medical imaging (3 medical X-ray pictures, 1 airport security, 1 CAT, 1 MRI, 1 ultrasound and 1 PET picture, as shown on Figure 4.1), discussed the students' familiarity with the them, chatted about their personal experience with medical imaging, and discussed connections of X-rays to visible light, ultrasound and other imaging techniques.

As in the previous study with individual students our discussion went through various physics concepts that students did bring into our discussion – light, waves, particles, spectrum, etc. At the end of the first part we focused our interview on comparisons between X-rays pictures (that were properly recognized by each groups of students) and the CAT scan slice picture (not naming it directly) and talked about the limits of information that can be obtained from these pictures. Also we discussed how the frontal pictures are different from the slices in a CAT scan. This discussion was our pre-activity diagnostic to which we returned after the lab activity was completed and used for qualitative assessment purposes.

### ***5.4.2 Teaching Part***

To address the issue of the electromagnetic (light) nature of X-rays, their different ways of interaction with the different types of matter (and also addressing geometrical issues that may arise during CAT scan image processing), we designed a small individual lab activity using Lego™ bricks.

The second part of our teaching interview started with each group of students playing the role of Lego™ physicians, in the same way that individual students did in the previous study. This activity formed an exploration in a Learning Cycle [Karplus, 1974], which was described in Chapter 3.

The Learning Cycle sequence was built around the most convenient concept - the ability of a material to block or attenuate light. Precisely speaking this ability should be separated into reflection, refraction and absorption, but we decided that for our purposes we do not necessarily need to discuss all these aspects while teaching students introductory image reconstruction.

We showed our students a box (Figure 2) which was closed by a non-transparent cover and which had sides made from translucent Lego™ bricks. We told the students that inside was an object of an unknown shape and it was made of the same semi-transparent bricks as the walls plus a non-transparent Lego™ "core" inside the object. We asked students, "*How we can determine the shape of this object?*" If the interviewees were not able to answer the question, scaffolding steps were provided. These steps included giving students a source of light (red) and a light detector (photovoltmeter). Then we asked the questions such as "*What can be an analog of creating an X-ray picture?*" "*What can you learn from measurements on only one side?*"

All the question sequences were designed in such a way that they would make sense to students even if their answer to the previous question was not scientifically correct (and the next question often served as a cue for answering the previous one - like the couple of the questions in the previous paragraph).

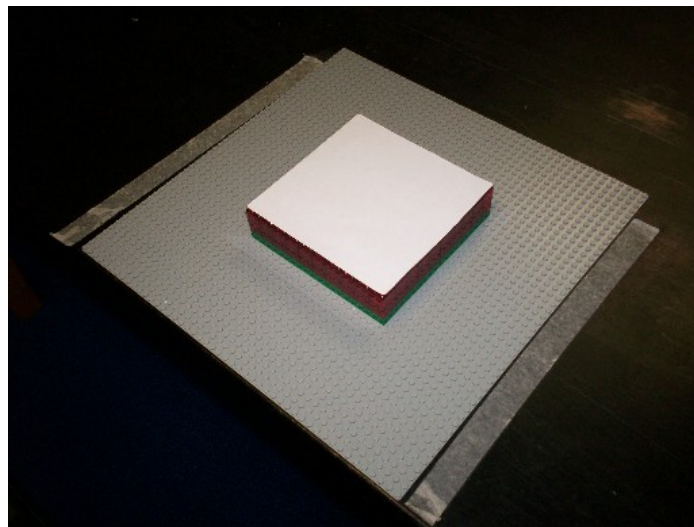


Figure 2: The setup presented to students at the beginning of the teaching part of the interview

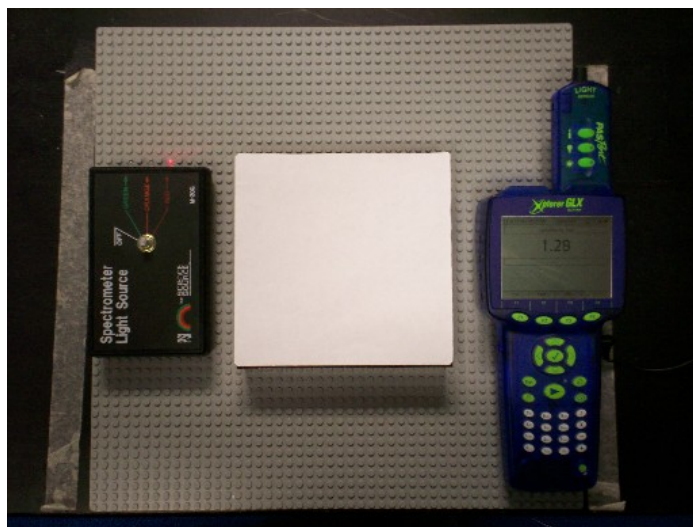


Figure 3: The light source (a light emitting diode) and the light reader (a Pasco™ PASPORT Xplorer universal meter) given to students after the beginning of the teaching part of the interview

As students went around the boxes with the light source and the light-detector, they were asked to record the intensity data as measured by light-detector (See Figure 4). Those measurements were, of course, lower when the light passed through the object with the amount of attenuation depending on the thickness of the internal object. Then, in a natural way, we asked the students, how, they thought, the readings of the light detector depended on the number of bricks through which the signal had gone through.

Another similar box, which the students were allowed to open, contained an object of a different form. (See Figure 6) If they had difficulties in approaching the problem directly, they could look at the task from a different perspective – and see directly how many Lego™ bricks are needed for getting a particular photovoltmeter reading (See Figure 5).

After all these scaffolding and thought-revealing discussions and the light reading measurements around the two boxes, the students made their final prediction about the hidden object that was inside the first box – and the box was finally opened (See Figure 7). Then a brief discussion of errors followed.

Then it was revealed to the students that what they have just done – stepping one dimension above in LED-“roentgenoscopy” - is just analogous to how CAT scans step one dimension up from regular X-rays, allowing us to make a full image reconstruction of the hidden

object. Finally the concept of Computer-Aided Tomography was explained to students directly. And again the general discussion about the activities, their order and relevance in the pre-med labs followed.

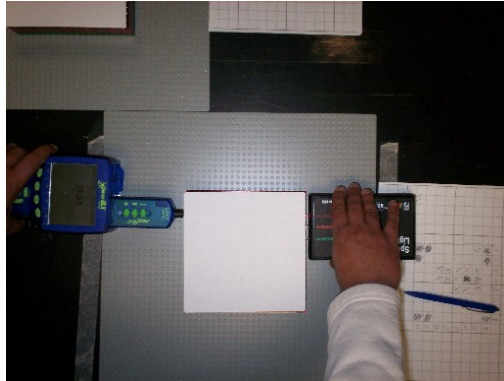


Figure 4: Going around the box with the light source and the light reader

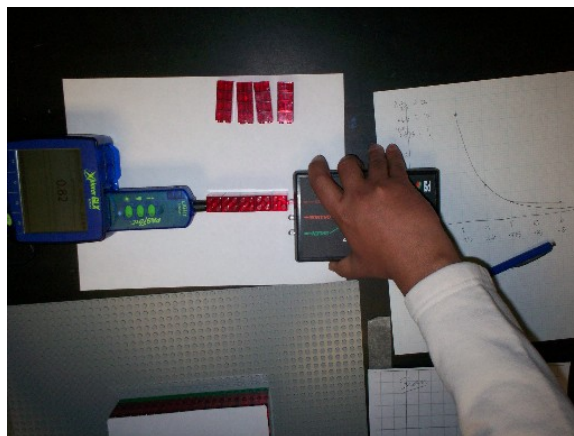


Figure 5: Determining how the light readings depend on the number of bricks through which the light passes



Figure 6: Presenting the second box which students are free to open any time

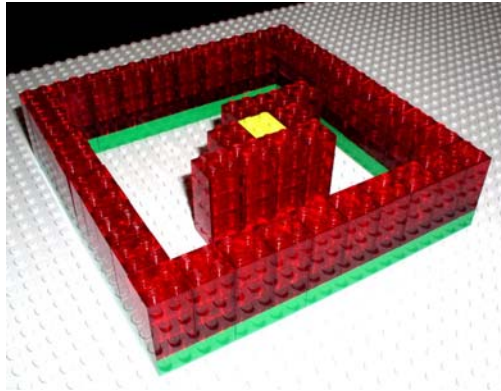


Figure 7: The box is finally opened at the end of the hands-on activity

## **5.5 The Interview with hands on activity and simulation - Phase 5**

### ***5.5.1 General Features***

Hasson and Manners [1995], who introduced a CAL (computer-aided learning) package for teaching elementary quantum mechanics, identified few advantages of using computer simulations as a method of teaching physics.

Students, studying a subject through a computer course, can advance at their own pace, skipping material that is familiar to them and repeating many time the modules with which they have particular difficulty. The use of computer allows a dynamic interaction between the student and teaching material possible, and this relation can be made flexible enough to accommodate a

variety of needs. This assists the learning process not only directly but also indirectly since the student's attention is simulated by both the interaction and the liveliness of the environment.

It is commonplace now that the computers have huge advantage over books and lectures but in our sequence we got a chance to compare them with hands-on activity which also allow for a great deal of constructive interactivity.

During the Phase 5 we incorporated the computer simulation [Ring 1999] into our routine. It had been done in two places:

1. The screenshot movie showing how the image is progressively revealed during the CAT scan was shown to the students right after the hands-on activity was completed by them. They were asked to tell whether they see any similarities with what they have just done. That allowed them to transfer.
2. Then, after the principles of CAT scanning were explained to the students, they were allowed to play with the simulation program themselves (with the help of the interviewer).

The whole protocol is included in the Appendix E.

After the interview students were asked to fill in the form, where they were also asked the questions about the Lego<sup>TM</sup> activity and the simulation program, how they thought these items helped them to understand how CAT technology works.

This form is included in Appendix G.

### ***5.5.2 Demographics of the Phase 5 participants***

3 groups of 3 students and 3 groups of 2 students participated in this concluding part of our research endeavor. 11 out of 15 participating students were pre-meds or other health-related majors, so every group contained at least one such student.



## **CHAPTER 6 Results of Clinical Interviews**

### **6.1 Chapter Overview**

In this chapter, we will describe interview analysis procedure and the various results of our clinical interviews – and all numerical estimations are made for Stages 1-3 (interviews with individual students).

### **6.2 Interview Analysis Procedure**

We used a phenomenographic approach to analyze all interview data which were described in the Chapter 3. Phenomenographic analysis [Marton, 1986] gives a variation of students' ideas rather than proves or disproves researchers' hypotheses about students' ideas. This strategy is in agreement with contemporary views of transfer - such as Lobato's Actor-Oriented Transfer model since the researcher does not prejudge what ideas a student might transfer, but rather looks for what, if anything, the student has transferred himself or herself. The categories from phenomenographic analysis then were synthesized using thematic analysis until the dominant themes emerged.

We utilized a procedure that is consistent with Colaizzi's [1978] seven steps of phenomenological analysis to analyze interview transcriptions. The seven steps are as follows:

1. We generated the transcripts of each of the interview sessions conducted. Our transcript consisted of the interviewer's questions, hints and prompts as well as of the verbatim statements, drawings and other written explanations made by the interviewee(s). This transcribing process made us more conscious of what Colaizzi calls the "subject's inherent meanings".

2. We looked through the data, trying to focus on the most important aspects of the studied phenomena, and extracted significant statements from the transcripts. These significant statements became the focus of subsequent analysis.

3. We took each significant statement and formulated meaning in the context of the subject's own terms.

4. We examined the associations constructed by the students in the different segments of the interviews and generated categories of each student's ideas. The meanings from a number of

interviews were grouped or organized in a cluster of themes, revealing common patterns or trends in the data.

5. We generated the themes by comparing the categories of associations across different students or groups of students. A detailed picture was created of the subjects' feelings and ideas on each theme (an "exhaustive description").

6. We prepared a description of each theme, which was supported by the different associations that students generated.

7. (not done) We were supposed to take our findings back to the subjects and see whether we omitted anything or not (a "member check"). However in our case we did not return to the student, but rather performed a member check during the interview itself. For logistical reasons, it would be extremely difficult to request the interviewee to return after all the previous steps of the analysis are completed.

But in steps 2 through 6 another researcher who is familiar with the goals of the research was involved in cross-checking my analysis. When we had disagreements, we engaged in a comprehensive discussion until we reach a consensus.

Also while doing this analysis and describing the results of it, we added some other observations and facts from our interviews that although cannot be strictly characterized as themes but nevertheless might be interesting and useful for our purposes.

### ***6.2.1 Credibility***

Lincoln and Guba [1986] defined credibility as the criterion in qualitative research opposed to internal validity in post-positivist research. According to them, the credibility test asks if there is a correspondence between the way the students actually perceive social constructs and the way we as the researchers portray their viewpoints. [Mertens, 2005]

Mertens points out a few strategies to ensuring credibility of researchers' interpretations of the perceptions of individuals of a given phenomenon. Among them there are prolonged and substantial engagement, persistent observation, negative case analysis, progressive subjectivity, and triangulation.

### ***6.2.2 Triangulation***

Triangulation means checking information that has been collected from different sources or methods for consistency of evidence across these sources of data [Mertens, 2005]. The main

rationale for it is to guarantee validity of interpretations of evidence. In this study we used two of the six triangulation techniques proposed by Denzin [1989]. These are member check and peer debriefing.

#### ***6.2.2.1 Member Check***

To increase credibility of our results, we must verify with the respondent groups the constructions that are developed as a result of data collected and analyzed. Mertens [2005] advised that at the end of each interview, the researcher should summarize what has been said and ask if the notes correctly reflect the person's position. But in our interview series, the verification was rather built in during the interview process. We asked the participants to elaborate on their explanation every time we felt that there could be various ways to understand their statements. Also, during our two interview series we always started the second session by asking students to summarize what they have discussed during the first interview.

#### ***6.2.2.2. Debriefing***

In peer debriefing we engaged in a conversation with peers of findings and conclusions. The members of our research group were also involved in the debriefing process during seminar presentations where we talked about our research progress.

#### ***6.2.3 Dependability***

Guba and Lincoln [1989] defined dependability (again) as the qualitative parallel to reliability in post-positivist research. Stability over time is expected in post-positivist paradigm, change is expected in the constructivist paradigm which should be tracked and publicly inspectable [Mertens, 2005]. Within this standpoint, we have maintained a research plan which has evolved in each step of the research process.

## 6.3 Results of the Clinical Interviews

We will express our results as the list of themes that emerged from students' responses, connected with the appropriate consecutive stages of our interview process. We will also explain why we consider these themes important for our purposes.

Some other results that could not be distinguished as "themes", as explained in the beginning of this chapter, will be also described near the closely related themes. Excerpts from the students' interviews illustrating our conclusions are given in quotes and italics. The words of the interviewer, if shown for clarity purposes, are underlined. Sometimes the coded words and expressions are bolded to better point up a described theme or adjacent topic.

### 6.3.1 *Familiarity with X-rays and ultrasound pictures, difficulties with the others*

This result was rather obvious and expected (and furthermore - it was one of the main motivations for this study), so we don't distinguish it as a separate theme, but it's still worth mentioning once more at the beginning of our discussion.

All the interviewed students recognized X-rays and ultrasound pictures although some after a couple of auxiliary hints. ("-Are you sure that they are all X-rays? - That's not an X-ray")

Students often could not recognize specifically other pictures, although pre-med students did distinguishably better than the other students (although not considerably better): *"It's like MRI or something similar... I am not sure"* *"This is a CAT scan of the brain or something like that"*. This was also a kind of expected result.

### 6.3.2 *"X-rays and Ultrasound Are Real, The Others Are Virtual"*

Many students tend to separate computer-generated images from, say, "more real" ones (although ultrasound pictures are also seen on the screens of computer monitors):

*"These are X-rays... these are sonograms... these are more **computer-generated** like"*

*"I think they are more **computer-generated**... and we going to have a clearer picture of the inside... and these are obviously kind of more simplified... X-rayed... these are showing better imaging... specifics... and these are just basic"*

Five students did it in some form at various stages of the interview without any special prompting. Probably this irrelevant distinction based on the blatant surface features (and rather

just misunderstanding then misconception) should be addressed somehow in our teaching module.

### ***6.3.3 Theme 1: From “knowing nothing” about X-rays to “knowing something”***

Many times we observed how the interviewed students started their discussion of X-rays with a statement that they “know (almost) nothing” about the topic or a similar one. Then, as we proceeded, they would make a transition to “know something” and even to “know quite a lot.” A part of the reason was that they initially felt they had learned nothing about the physics of X-rays in their physics classes. However, as we progressed through the interview, they feel that they were free to bring to our discussion resources from other classes and thus concluded that they did know quite a lot.

*“I would say I know **nothing**. They detect... doctors use them to find fractures in the bones, look at the bones structure... any abnormalities... but they also use scans to do that so”*

*“**Nothing**... I can guess some ideas but... I wouldn’t say much about it... I am not really ... about that....recently **I knew about it, but I forgot**... Let me try to remember... I knew recently the very details of this”.*

At least ten of the interviewed students (and at least three among pre-meds) revealed this tendency. After declaring their “ignorance” (and sometimes even frustration) students then showed the significant progress while their mental models were built during the course of our interview and the details of these consequently constructed while students transfer these elements for these models from different sources are described below.

Hammer and Elby [2002] described two kinds of personal epistemological modes – “knowledge as propagated stuff” and “knowledge as fabricated stuff,” between which students may switch in their learning process. These epistemic modes affect student’s thinking, transfer and model-building a lot and in our case we see that switching from the more traditionalist “propagated stuff” to the more constructivist “fabricated stuff” using our interview materials; cueing and scaffolding improves their learning a lot.

### ***6.3.4 Theme 2: Focusing on safety while discussing their own experience with X-rays***

When we asked students to discuss their own experience pre-med students are more focused on safety features than on any other details: *“You have to wear a **protective**... because*

*X-rays are so strong...” “They put like a waist on you if you are a woman...to protect everything”.*

Even when discussing their experience all the students focused on hazards of X-rays – remembering – even if they couldn’t recall much more.

*“How do they get the picture? Yeah, they put the film under here, right? I don’t, here is one who comes and sees... I don’t know much about X-rays... oh, Gosh... I recall they put like a vest on you... or like X-rays in the dentist, yeah... They put on... the reflective... so it doesn’t harm the rest of your body... just like a flesh... that’s what I remember... And for a very short period of time... I don’t remember much else.”*

This result also looks very significant - since our interview protocol purposefully did not emphasize the safety issue and we did not cue students toward this discussion. Student are so aware about the risks of being exposed to X-rays that it often affects their model-building process a lot.

### ***6.3.5 The importance of historical perspective***

Again we do not distinguish this result as a separate theme – but while not widespread we think that this outcome is also very important. Some students transferred their knowledge about history of science - three of the pre-med students did it in some form. One of the most exemplary excerpts is here:

*“Marie Curie did a lot of work on X-rays... She and her husband Pierre did a lot of work with discovering it... Like they had a rock that was radioactive... I think it was uranium... But they did a lot with radioactivity too. That was kind of an accident... they just left the paper and they got an image from X-rays... and she ended up dying from cancer... because she did a lot of work with X-ray... because you know... they are very damaging. With X-rays as soon as you turn it off, the machine you are safe... it also can be blocked by lead aprons and distance will help reduce your effect.”*

Although (like with other historical references presented by students) it was not historically quite true (and did not correspond to the real historical picture, outlined in the Chapter 2) this historical interest and awareness definitely was accompanied with students knowledge about X-rays and adjacent physics topics and positive attitude toward our materials. The historical accounts should definitely be added to our teaching modules.

### 6.3.6 “X-rays are flow of energy”

Four students used the expression “flow of energy” (or “flux of energy”, “type of energy”) while describing X-rays, both while discussing X-rays themselves and comparing and contrasting them with other imaging techniques, while none of our interviewees used such terms describing other imaging techniques:

*“I thought that it was like some **flow of energy**... but **type of energy**... I’m not quite sure... like what type of rays it is... because you have reactive particles like alpha and beta... but I’m not sure what is an X-ray, like what’s being emitted... sometimes you have electrons coming out sometimes you have protons... I’m not sure what an X-ray is”*

It of course not a misconception; it actually a right part of student’s models of X-rays, but we definitely should address it somehow that, for instance ultrasound is also a “flow of energy” although students did not use this term in their descriptions, probably because they had better and more specific ideas about sound waves (it is discussed later).

#### *i. Theme 3: “Density Determines Visibility”*

One of the most striking findings was the omnipresence of the term “density” as a part of explanations of why we can see some objects using X-rays and cannot see others. In all three phases (and later during the Phases 3 and 5) almost all students and all groups of students brought density into the discussions without any prompting from the interviewer. Only one student from Phase 1 (for whom Concepts of Physics was the first physics class in her life), did not use this concept in the discussion. Since this is the most “overwhelming” result of our analysis we provide here a lot of illustration from students’ transcripts with all the varieties of appearance and prevalence of the density idea:

*“Like basically... to look inside... to actually see when they look at the bones... there are **dense** sections... and there are sections that not **dense**... they have to distinguish between the two... basically.”*

*“The higher the energy and the frequency – the better it penetrates, that’s how it’s with X-rays, it can penetrate through your skin, and like it bounces off those **denser** things... like bones... and when you have it on top of the... film... what happens that if it comes in... interacts with the bones and this interaction... I know that it waves and particles... so the wave comes in*

*and I don't know it's like refracts or it passes through... but anyway this wavelength coming through and interacting with this particle and exposes this on the film"*

*"The X-rays pass directly through the skin and the **denser** material such as bones and the ring which is incredibly dense – it just backs them off – or not necessary right back just skew their path."*

*"I think it's... the **denser** something is... the more likely it's going to show up... so even when you see osteoporosis and an X-ray, it's dimmer – it's not so bright, it doesn't show up, you can see weakness and you can see when the bones become **less dense**, comparing it to other bones that doesn't show up as well... so yeah, I think it has to do with the density of the material.*

In the following subchapters we continue to discuss this theme.

### ***1. "Bones are denser, softer tissues are less dense"***

Students at the same time tended to automatically assume that bones are denser while softer tissues are less dense:

*"Oh, Jeez... I think this is showing like it's more **dense**... I don't know how they do this... you can also see like organs... so I guess **density** is low.."*

*"Because in the bones they comprise out of **dense** sections... that are different from **non-dense**... and they distinguish between the **dense** and **non-dense**... that's why it's white and black"*

*"Because it's only... see... like the bones they are **dense** than the skin is... Why we see them... I don't even know."*

*"Bones are **dense** and other tissues obviously are going to show up as lighter or less **dense**... other tissues may not be so clear, bones show up much more clearly because... I assume being more **dense**... these interactions may be... it cannot just pass right through it... 'cause you definitely don't use X-rays to look at... organs, because you don't get a clear picture"*



### 6.3.7.2 “Density idea is dominant but not strong”

When challenged by the follow-up questions like “Why do you think it’s density?””, “Why are denser tissues of our bodies less visible?” students sometimes started to come up with other ideas:

*“Not necessarily **density** but just the **composition** of the material itself.”*

*“Or may be just because of the **structure** of it? **Permeability**, I guess. But I think it has more with the **density**.”*

*“Different **compositions**, different **components** X-rays would pass through the plastic... and would be absorbed by the metal objects (This answer came at the later stage of one of the interviews, while we discussed the airport security picture).*

When students continued to stick with the density idea, our follow-up questions revealed that, if they were able to elaborate on the concept of density, they did not necessarily mean regular mass density from mechanics textbooks. Pre-med and engineering students usually implied something different such as concentration: “*particles are packed denser,*” “*molecules are closer to each other*” so these particles or molecules “prevent” X-rays from going among them.

During the Phase 2 we probed pre-med students understanding of density and its relation to seeing objects with X-rays, with a following challenging scenario: “Let’s consider glass, wood and visible light. Glass is denser than wood (it sinks while wood floats), but light cannot penetrate wood and obviously can penetrate glass, which is transparent. Why do you think that it will be different for X-rays?” At this point, almost all students (except for two) tended to leave the density idea and replace it with “solidness” or “concentration” or with some general idea like “composition” “type of material”.

A few times students tried to make more elaborate explanations, taking into account for instance specific compositions of the substances:

*“The... let’s see... skin... it contains atoms like hydrogen... oxygen... but bones have a higher **density**... heavier elements like calcium... or metal for that ring... and X-rays I guess they are absorbed better by heavier elements.”*

Two pre-med students transferred medical knowledge, invoking the same density idea:

*“I mean it’s – someone with osteoporosis – their X-rays are going to look different than a healthy 20-year old male or something... just the **density** of the bone... the different minerals that it consists of...”*

Sometimes their arguments were kind of strange and not exactly true (rarely is wood denser than a metal) but the concept still helped them to avoid overrelying on density. Here is the answer from one of these students, also pre-med:

*“Not necessarily **density**, because wood for instance can be fairly **dense**... more than some of the metals... but X-rays passes through wood easier than through metals... I don’t know necessarily why but I think yes... I don’t know if it has to do with **density** or **reflectivity**”.*

We can refer to the results, where students easily invoke the density factor, while discussing the property which is not easily explainable by them (visibility), to the work of Wittmann & Scherr [2002] who investigated the effect of a student’s epistemological mode on her reasoning in an interview about current and conductivity. The student was asked what “category” (conductor or insulator) Styrofoam belonged to and the answer was “*Insulator*”. When asked why, she stated that she had “*memorized it!*” When the student was asked to clarify the property of Styrofoam that might lead to its insulating behavior, she referred to the “*little density thing*” and added that she did not “*really know*” the answer.

### ***6.3.7.3 Tendency to explain visibility by local characteristics***

Still, we can say that students tend to explain the visibility of tissues with local characteristics (whether it is density, concentration or some other similar property or parameter) ignoring the fact that X-rays actually go through a number of different tissues with different densities, solidness and concentrations and we needed to do something special to get information about some particular small details. Since this is conceptually an extremely important image processing issue, which potentially can produce many confusions and mistakes, it later became one of the most important concern that we addressed later during the Phase 3-5 teaching interview series as described below.

#### ***6.3.7.4 Other explanations for visibility***

Two students (one pre-med and one future engineer, who also of course expressed the above mentioned “density” idea) tried to associate penetrating ability of X-rays with their wave properties:

*“Some wavelength can penetrate deeper and some penetrate a little bit and then stop... I would guess that the wave would keep traveling until it meets a certain density... And once they do that they cannot go any further.”*

Some of the students (particularly the engineering majors during the Phase 1) revealed later that they knew quite a lot about inner atomic structure and two even mentioned how X-ray electromagnetic waves can correspond to the different energy levels in atomic spectra. But since it wasn't the case with pre-med students we decided not to elaborate on this topic. But in future follow-up studies we can pursue this issue – we will talk about it in the last chapter.

#### ***6.3.8 “Ultrasound is able to see softer tissues than X-rays”***

This result was also sort of expected. The majority of students also recognized the ultrasound picture. (Only three of them during the Phases 1-3 did not at the beginning – none of them was pre-med but after we identified it to them, they “recalled.”) So, the natural question was *“Why do we need both – X-rays and ultrasound? Why can we not see using X-rays the things that we can see using ultrasound?”* Here we somewhat deliberately led students toward discussing imaging aspects of both technologies (while not providing any cues about their hazards). But still students could be divided in two comparable groups according to their responses – some of them concentrated on how dangerous X-rays are and some instead mentioned that ultrasound can see softer tissues. We don't make any quantitative estimation here, because it was a little too vague to categorize, but both tendencies we expressed in approximately equal numbers.

### **6.3.9 “Ultrasound is less dangerous than X-rays”**

While all the students heard something about hazards of X-rays they never heard about dangers of ultrasound, and that fact contributed to their reasoning a lot:

*“I thought that ultrasound was like using sound... but I don’t know how **damaging** the ultrasound is, I never really heard anything... because with X-rays I have to take a lot of **precautions** and you want to limit the exposure... With ultrasound I’ve never heard that... so I am thinking that it’s OK*

(Although one pre-med student mentioned using ultrasound equipment for making home fetal videos is not approved by a US governmental agency, but she was not sure whether it was for the safety reasons or not.)

#### **6.3.9.1 How an ultrasound machine works**

Here is a typical answer about how an ultrasound machine works from a pre-med student with some relevant pre-professional job experience:

*“The most typical example is a pregnant woman... you use it just to image a baby... this is a pregnant stomach and the baby is in the uterus... and so you put this on stomach... and I mean this is connected to the monitor... whatever... but this I think it meets high frequency (or high pitch) sounds... and those soundwaves... again interact with the fetus... which is going to be more dense than... like the rest of the uterus... so there is just the difference... and.. again some kind of density here... a higher concentration of cells, particles, higher concentration of particles... we going to get this image because the soundwaves are going to interact differently with the fetus and with the rest of the uterus. And so we have this imaging, as a result of interaction between soundwaves and particles.”*

Often students gave unprompted references to the safety of ultrasound:

*So lets’ see... I am not too familiar with ultrasound actually... My understanding that it’s sound frequencies... what we can hear... and they are refracted... reflected differently.. from different tissues... That’s about all I know about them... I think we went over them in Physics... if I remember right... Ultrasound is generally used or commonly used for pregnancies.... X-rays have their downsides... that they are ionizing radiation... they can damage DNA.. the fetus*

Usually students gave a very general description of the ultrasound:

*I think it's just the way the sound is bouncing off your body that gives the image. And that's pretty much what I know about ultrasound... I know you can see more like fluffy things... you aren't seeing the skeleton as much."*

Students who had experience with ultrasound focus more on details:

*"Ultrasound... it's usually a machine that rubs... I have seen it on shoulder... so that's... I don't know exactly how it works... but it's used as an imaging process also... locate muscles and also... I guess my taking on how it would work... but I don't really know for sure... because I have never been... around them? ... Because ultrasound I think is going to be less damaging... especially with the baby... and it doesn't go all the way through... you can see a part of it... while here you see the entire bone... structure."*

Again pre-med students often expressed frustration with their knowledge, which was not the case with other students even if they knew less:

*"They have like the monitor, that's what is going to do is pick up the interaction of sound waves with other tissue, and somehow... they probably have a couple of different tools that they are using here on the stomach... and... I don't know... I have no idea... I feel so stupid... I don't know."*

The main thing that we conclude from these results here that we definitely should use pre-med experience with ultrasound equipment and their general familiarity in our teaching module. The question of proper placement of ultrasound materials among the materials related to X-rays and CAT-scans remains open but we should definitely take into account the students' ideas that are expressed in the quotes above.

### **6.3.9.2 Other differences between X-rays and ultrasound**

Students sometimes without any prompts mentioned other characteristics that distinguished X-rays and ultrasound but they already cannot be easily categorized. One of the interesting excerpts is here:

*"Ok. I don't think that sound waves have any polarity. And I know that light waves do... because when you use like sunglasses or something. dark and you take out... so light is both horizontal and vertical... so if you use something. that like a shade or sunglasses OK that takes out the vertical rays then hits this and all we get is this... so transverse is... one of them is just one way... and the other one is combination of both... light I know is a combination of both... because it obviously displays polarity and we are able to filter it."*

It was the only case when “polarity” was mentioned. This is an example of a rare interesting idea about which we cannot make a definite answer – whether it can help us or not but it worth further research.

The idea that ultrasound makes “continuous measurements” while X-ray pictures are “still” was expressed by two students without any prompts:

*“Because it’s like a camera, once it’s on it continues... and this X-ray is just short... like you take a picture... So this is continuous and this is not... you are not going to see movement in this.”*

This difference is obvious to anyone who had some experience with both ultrasound and X-rays (and the majority of pre-med students fall into this category) and it was rather to our surprise that it was mentioned only once – this observation shows that students may not transfer automatically the facts that are very well known to them but still can readily recall and utilize them after hints.

#### ***6.3.10 Theme 4: “Transfer of sound properties to ultrasound and light properties to X-rays”***

Pre-med and engineering students easily transferred the known properties of ultrasound to sound and (usually with some prompting) the properties of light to ultrasound.

Almost all students knew (or at least easily assumed) that ultrasound is similar to sound and all of them (except for one student from the Concepts of Physics class) knew that sound is a wave. Our interviewees successfully and properly transferred almost all of the sound properties that were known to them to ultrasound, although how exactly ultrasound pictures were produced remained rather a mystery to them:

*“Let me see. We have sound waves and we see... What is the difference between sound and ultrasound? I think ultrasound is maybe very high... something ultra... ultra wave I don’t know... ultra frequency of it... I am not sure, I don’t know. I need to learn more.”*

*“Just based on prefix ultra you would think that it should be higher than hearing level, so it will be higher frequency or high pitch... and I don’t know how frequency relates to sound... but it would be a higher pitch”*

The range of these sound and light properties was of course very diverse, sometimes students only knew that sound or light is a wave and has a frequency, sometimes they gave an

elaborate bunch of properties, right or wrong, but didn't have any difficulty transferring these properties to ultrasound and X-rays (with the notable exception of color property, of course). Some of the noteworthy ideas are pointed out below.

#### **6.3.10.1 “Sound travels faster in a denser medium”**

When prompted by follow-up questions to discuss how sound and ultrasound travel in media of different densities they easily stated that sound travels better (faster) in denser media.” *Sound travels better in a denser medium... the denser the better.” “So Density. More dense the medium the faster soundwaves travel.”*

Five students mentioned this in some form.

#### **6.3.10.2 “Sound from vibration, light from energy”**

When asked the contrasting follow-up question “How is sound different from light?” students often tended to associate sound and ultrasound with “vibrations” while light and X-rays with “energy” (as already mentioned above)

*“With X-rays it’s something that’s emitted... It’s hard to describe if you aren’t an expert in this, I guess... But with X-rays you have these waves of **energy**... but this (sound) from **vibrations**... I’m not quite sure... and this (X-rays) is more like particles and this, ultrasound, has more to do with vibrations... this is more of vibrations going on in atoms but I’m not sure”*

*“How is sound different from light? Sound is... like light is energy and sound is **vibrations**... but this (light) is a form of energy also... yeah... and so... like when you here... inside... you are hearing... some noise inside of the body.”*

But also students were transferring different "signature" features and concepts related to light (or to electromagnetic waves), expressing this distinction using different terms such as “radiation”, “photons”, “particles”, “perpendicular magnetic and electrical fields” – all these characteristics and objects that they didn't associate with sound or ultrasound at all.

#### **6.3.10.3 “Ultrasound cannot propagate through empty space, X-rays can”**

Two engineering students and two pre-med students without prompting said that sound required media to propagate and light does not require it and can propagate in empty space. Only two pre-med students could not make this distinction when prompted to talk about it explicitly. Although we did not make in our interview a connection between this distinction and the fact

that X-ray imaging does not require direct contact while an ultrasound sensor should be applied directly to the body we think that in our teaching module this difference also should be taken into account and explained.

#### **6.3.10.4 “X-rays are much faster than ultrasound”**

Students very easily transferred all the sound properties they knew to ultrasound and many light properties to X-rays, starting with the speeds of both. Although they often made mistakes, like assuming that ultrasound might have higher speed instead of higher frequency in comparison with “regular sound”:

*“The speed of light I want to say... something like...c equals like 6 times 10 to the 20 seconds meter... something like this. Sound is obviously slower... I remember it’s significantly slower... but I don’t know what... at what speed it travels... although with ultrasound it’s probably ultra... higher speed maybe.”*

But with proper follow-up questions, involving some commonsense and dimensional considerations, all pre-med students were able to figure out the proper relationship among frequency, wavelength and wave speed of X-rays and ultrasound.

#### **6.3.10.5 “Vibrations in ultrasound”**

Although the vibrations are the essence of sound and students usually understand it well (with notable peculiarities [Hrepic, 2004]), only rarely our interviewees made a direct connection between vibration and imaging properties, it happened only two times:

*“This one is used more for like skeleton system... this one is more to see the organs ... this is something about the sound and how it vibrates, when they do this, right? The vibration, I don’t know.”*

#### **6.3.10.6 “Sound doesn’t belong to the spectrum”**

When asked a “misleading” question whether sound can be put anywhere in the spectrum almost all students (and all premed students except for one) understood that it could not.

*“It’s soundwaves. Very high frequency soundwaves. It’s not the electromagnetic radiation”*



One pre-med student put ultrasound on the radiowave part of the spectrum; one non-science student from Concept of Physics did the same thing, arguing that “*radiowaves transmit sound*”.

We think that although this misconception is not very common, probably it’s very exemplary and also worth addressing in our X-ray teaching module.

### 6.3.11 Confusion “*transverse – longitudinal*”

Some students pointed out, without prompting, the differences between transverse and longitudinal waves although sometimes they could not recall or figure out which of them were X-rays and which were ultrasound.

“*Light is transverse, I believe and sound is longitudinal... or the other way... I might have these confused... but one is longitudinal and one is transverse...*”

“*Longitudinal I think we are going like that... and transverse... what is transverse? May be more like this? Or just straight through? Like... One has waves... I forgot the difference between longitudinal and transverse*”

“*Like we said light is transverse... what’s going to happen... even X-rays I think are probably transverse...*”

Sometimes students made some not obvious connections between concepts – like “transversity” of the waves and their ability to travel through vacuum:

“*I think they have to be transverse to be able to... like... solar radiation has to be transverse to be able to travel through vacuum... and get to Earth*”

This student was not able to justify his conclusion after the follow-up question, retreating to “*I just remembered it*”, which our interviewees did often but usually not with these strange conclusions.

And there is another very exemplary dialog:

Student: “*Sound is a longitudinal wave, right?*”

Interviewer: *Yes. And what about electromagnetic waves?*

Student: *It’s different, I don’t remember how it’s called.*

Only one student proposed that X-rays might be a longitudinal wave, not a generalizable result, of course, but it can be referred to the initial ideas of Roentgen himself, described in the Chapter 2.

### 6.3.12 Theme 5: Not knowing the order for spectrum

Students usually easily recalled the spectrum as the thing that “unifies X-rays, visible, light and other similar things” – after some cues or even without cues almost all of them (except for two Concepts of Physics students) called it the spectrum eventually.

*“I know... UV, microwaves, X-rays, gamma-rays... I don’t really know where they go though... I don’t know which side of the spectrum they are... I would put X-rays right here but I don’t really know. If they are really longer... may be longer wavelength can penetrate skin more... May be it kind of makes sense since UV is there.... I think it’s penetration ability”*

*“I don’t remember where they go specifically... UV, infrared... somewhere there”*

*“Gamma, X-ray... UV, IR... I am trying to remember is there anything between IR and radiowaves”*

Figure 8 shows one of the exemplary spectrum pictures where a student initially put X-rays on the long wave edge of the spectrum then put it on the opposite, short wave edge, but still thinks that ultraviolet radiation is stronger and consequently corresponds to ever shorter wavelengths.

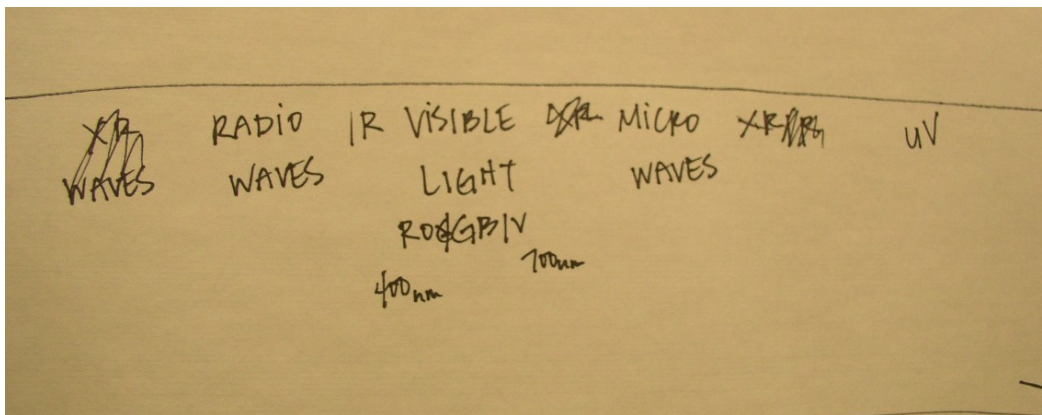


Figure 8: One of the spectrum picture given by an interviewed student

Below we present some elaboration of this theme:

#### 6.3.12.1 Theme 5 (cont.): Frequency, wavelength, energy, strength of X-rays

So, those students who successfully invoked and transferred their knowledge that X-rays are part of the spectrum often could not recall whether X-rays belong to the longer or shorter wavelength part of this spectrum. They even tended to put them mistakenly in the longer

wavelength part of the spectrum, apparently making the association "longer - bigger - stronger." Here we can talk about the p-prime "longer-stronger" [diSessa, 1993]. The characteristic of wavelength came into their mind much more easily than frequency and this fact affected their further conclusions a lot. But when prompted to think about other wave characteristics of X-rays - like frequency - those students who had chosen longer wavelength for X-rays tended to change their opinion.

Now higher frequency was associated with stronger, more dangerous waves including X-rays. So with just proper questioning, staying within the format of semi-structured interview, without providing students with any leading cues, we can direct them toward right ideas.

*"But I can't remember where it would be. For some reason I believed that **shorter** was **more damaging**. May be it will go over here on the shorter end of the spectrum..."*

Three times students explicitly said that confusion:

*"If I remember correctly... I **always get them reverse**. But I always though red was on the shorter wavelength, and then you get more into your purples... this is where I think I reverse it a lot ... and then you have intermediate colors... I think that infrareds are way over here, and I am not so sure whether it's beyond this level... but sometimes I reverse... can't remember."*

Two times students associated power or strength (and consequently hazards) of electromagnetic waves with their intensity:

*"The wavelength continues to grow... and so does the intensity and the adverse effects."*

We think that this misconception, although probably not so widespread as we might expect, is also worth addressing in our teaching module.

#### **6.3.12.2 Theme 5 (cont.): "Ultraviolet is more damaging than X-rays"**

We already briefly touched on this issue. Three pre-med students believed that ultraviolet radiation (together with gamma radiation) is more damaging to us than X-rays (and most of the other parts of the spectrum). They connected it with the hazards of solar radiation: "*UVs obviously do some sun damage*"

It contributed to their improper positioning of the ultraviolet and X-ray parts of the spectrum:

*"- So do you think that X-rays are more damaging than UVs?"*

*- No, I think ultraviolet are more damaging, I would put them back...and X-rays here... I think that infrared aren't as damaging as ultraviolet.*

Two pre-med students demonstrated a substantial foundation for their view, transferring their pre-professional experience:

*“- So you think that UV is more energetic and dangerous than X-rays?”*

*- Yes... I would think so.... There are a lot of radiologists that are doing it every day for their job... but if you have to sit at the sun for your job it would be much worse... that's why I think... obviously there is a limit... and healthy way”*

But more knowledge definitely helped other students to move the ultraviolet part to the weaker side of the spectrum:

*“So I am pretty sure that ultraviolet isn't classified as ionizing radiation... probably.”*

And after a couple of follow-up questions we heard from the same student:

*“- And why do you think after a certain frequency it starts to be ionizing? - They have enough energy to actually cause... reactions... like oxidizing reactions... knock electrons out ... away from the molecules... atoms.”*

The comparison of ultraviolet radiation and X-rays and fixing possible students' misconception here also will look very appropriate in our X-ray/CAT-scan teaching module.

### **6.3.12.3 Theme 5 (cont. ): X-rays and Gamma-rays parts of the spectrum**

Almost all the students did not make mistakes putting gamma-rays on the strongest edge (only one pre-med student forgot it), even if they underestimated the dangers of X-rays and misplaced other parts of the spectrum:

*“I don't know what's with X-rays today but gamma-rays can do **a horrible damage**... I think they will be able to pass right through... the cells, the bones, the tissues...”*

Alpha and beta-radiations usually were mentioned by the students when they were prompted to think about other forms of radiation that is similar to gamma-radiation but they usually were not sure what exactly they were.

*“I guess that just talking and more getting around back.. it kind of reminds me... may be it was that. Electromagnetic... I don't know whether it's electromagnetic or not. We have ionizing radiation and non-ionizing radiation and stuff like that... but how exactly it fits in the spectrum I don't recall... it's not something you see every day... I probably have seen it once or twice and never really was tested on it. Just went out of the door.”*

Four of six pre-med students with whom we had this kind of follow-up discussion were sure that alpha- and beta-radiation were not part of the electromagnetic spectrum although only

two of them we able to say specifically that these forms of radiation consist of particles like electrons and protons.

### ***6.3.13 Some other auxiliary discussions and findings***

Here we present some other results that might be important for the X-ray/CAT-scan module curriculum developers:

#### ***6.3.13.1 Doppler Effect and ultrasound***

Only two students mentioned that when using ultrasound we can see moving objects (although the Doppler Effect was not even once brought into our discussion by students). When we occasionally started discussing the Doppler Effect, students mentioned different applications – from astronomy to meteorology but never made any unprompted connection to ultrasound imaging. This situation was observed again with pre-med students in Phase 2.

### 6.3.13.2 Other applications of X-rays

Three pre-med students without prompts mentioned also therapeutic applications of X-rays, while two engineering students mentioned X-ray astronomy (one of them in follow-up discussion mentioned Chandra Observatory X-ray Telescope Project, information about which he had got from the Discovery TV Channel).

### 6.3.13.3 Particle-Wave Duality

The particle-wave duality issue arose with five of our participating students (two engineering and three pre-meds).

*“Light is able to do certain things because it’s **wave** but it’s able to do other things because it’s **particle**... and I remember... with not being completely wrong”*

One of the interesting unprompted and unexpected responses of a pre-med student was:

*“I am thinking shorter waves will show more **particle** properties. Just because you will have them more bunched up – like this... if you think about them as **waves**... and I always thought that they do more damage than these... may be... I think that’s all... that I know about that.”*

The same student who gave an extensive historically-informed answer about Marie Curie, which was described few pages ago, also tried to give more narrative description here:

*“I used to be confused by that because I thought... May be it was Einstein who first said that may be they are **photons** or something... or tried to describe them that way... and that later on somebody proposed that they might be more like **waves**... that’s what have I thought but I am not quite sure, I thought that it’s just a like we can think of them as being **photons** and now people tend to go more with **waves**. It gets kind of confused by which one... which way is... or it can be described equally both... because no one really knows for sure how is it... At least I am not sure.”*

We are not sure that the introduction of the relatively complicated concept of particle-wave duality is immediately appropriate in our teaching module but the issue is worth further studies.

### **6.3.14 Theme 6: Not knowing much about any other imaging techniques**

Students' knowledge about any other imaging techniques was at best very sporadic. In the majority of cases they also couldn't distinguish which of the shown pictures were CAT scans, MRIs or PETs.

*"There is...you can do CAT scans, MRI or what is the right word... I may not use the right word?"*

*" I know there are CAT scans but I don't know whether they are versions of MRI or there are different from MRIs... I know MRI just magnetic imaging... I really don't know a lot about any of this... I haven't really learnt much about any of the actual techniques"*

*"MRI... It takes special... like micro... I don't really know the word for... but it's like slices... like your bones... individual parts of your bones... so you can see like... different parts of the bones... and to see any issues..."*

*"Just a computer assisted something, just the same basic things as.... Kind of the same principle as MRI"*

*"- Do you think these CATs are more similar to ultrasound, X-rays or MRI?"*

*- More similar to MRI, I think, I am really not sure, I don't know whether I actually have seen a picture of it. Maybe I have, but just didn't realize that it was it... I am not sure what is the difference between MRI and the CAT scans. I thought these were MRI but I might be wrong. MRI can see softer tissues but probably CAT scans can see them too. But I never saw a picture that says this is CAT scan, this machine produced it, you know."*

They also tried to rely on their personal experience with CAT:

*"CATs... a doctor he showed me a lot of things on my computer... but I don't know what he is using to take his pictures... but you can do a lot of things"*

A couple of pre-med students who had learned something about MRI did not feel certain and enthusiastic about their knowledge, although it had direct application to their future profession, one of them even hated it:

*"CAT scans – they look like at litigated tissues, the softer tissues of the body. MRI is like NMR, if I remember it correctly... and that what is so weird about it... I hated NMR when I learned it. I know it helps you visualize it because it looks like.... But I can't remember. But I know it's somehow related to it... but I cannot relate it... the resonance... something like resonance... I really cannot give you more details..."*

While trying to decipher the abbreviations for that advanced imaging techniques students usually were “almost successful”

“-Do you remember what it stands for, MRI?”

*- Resonance is the R, I think. May be magnet or magnetic. And I – what is it – interface or something... CATs? Computer Axial tomography?”*

Two of the students expressed an interesting idea that “more penetrating” technologies would actually show us less information:

*“MRIs are like magnetic and CAT scans... and don’t remember what is it... but I think... it obviously shows more than an X-ray... so I would believe that it penetrates less than X-ray does.”*

Students tried to make general conclusions about these imaging techniques while not being able to rely on their knowledge:

*“I think they CATs and MRIs are all similar, they just have different avenues, where they work best... They are similar... they are able to define a structure that obviously cannot be seen... but how they are different is the method how they work I guess... But I don’t really know enough how CT versus MRI and PET work... and why one is better than another under certain circumstances.*

Sometimes students tried to give more extensive explanations of the three advanced imaging techniques, The typical examples are:

1) for MRI:

*“MRI gives more of a finer distinction between the materials... something... for instance on the X-ray we look pretty much the same... the brain material is very similar... and ultrasound will give us just a blurry mess. The MRI senses specifically what kind of cells... the chemical makeup... in one area of the brain versus another... and... yeah.”*

2) for PET:

*“It’s very good for showing brain like... I think it measures metabolism it is kind of helping us image what areas of the brain are functioning... Although I don’t really know how it works. I mean I imagine that probably what you are doing is since it’s positron-electron whatever... it’s a beam of electrons I assume... and... this is the one that interacts with like hydrogen... molecules”*

*“You use PET to look at the brain, X-rays to look at bones.”*



### **6.3.15 From where students transfer? - High School and Other Classes Sources**

Students typically regretted they haven't learnt much from their physics classes, especially from college physics:

*"- Have you studied anything about X-rays in this courses? - **No**... The only time when we touched one... waves and the energy... would be in **physical chemistry**.... The only stuff I could have seen... this stuff is just from physicians... and even they don't give a lot of information about what is going on."*

*"I have heard about X-rays in **chemistry** before... but I never really learned... what's different between them and UV light."*

Even if they remember something:

*"Maybe we did go over... with **nothing specific**... no information about X-rays when I took my MCAT and there was a passage about X-rays... that's why I know more about that that from **physics class**, I don't remember I learned much about X-rays in **physics**"*

Pre-med and health-related students tend to rely more on their other classes (like chemistry).

In general, students relied more on their high school conceptual-level knowledge from which they, for instance, usually retrieved and transferred the key spectrum idea (one students recalled the spectrum scheme from the science classroom wall) that governed their whole discussion about the subject.

*"I think that's all I know about it the general stuff that I learned from **physics in high school**. "*

Among college classes, others physics classes were often much less valuable than the other classes like chemistry, biology, biochemistry, radiology, radiation safety and others.

*"I think we had it... like in **ecology class**... and it seems like **biology class**... in one of them we talk about it but... may be not".*

### **6.3.16 From where students transfer - Some other sources of information**

Apart from their own experience with medical imaging equipment as patients or pre-professionals or science (physics or non-physics) classes, students often mentioned other sources

of information – mass media (The Discovery Health channel was talked about twice, other TV programs and popular newspaper articles were brought up).

### ***6.3.17 Differences across different groups of students***

As for the demographic differences, we did not notice much qualitative difference between engineering and elementary education majors during the Phase 1, although math preparation of the former was apparently much stronger. Calculus-based physics students were apparently much more knowledgeable about the general physics topics than the students from the Concepts of Physics, but that did not help them much to build up a coherent model of X-rays. Approximately the same level of knowledge was demonstrated by pre-med students who participated in Phases 2 and 3, although they demonstrated much more enthusiasm, and often transferred their pre-professional experience with medical equipment to our interview.

### ***6.3.18 Relevance of the medical imaging topics in college physics classrooms***

Virtually all pre-med students saw the real importance of teaching medical imaging in college physics classes:

*“For people, I mean, clinical correlations obviously are going to be great. I mean learning about kind of imaging that we are using... I don’t have a really great idea... how this... but knowing and being able to apply what I am going to do would be really great.”*

Two pre-med students mentioned medical research and looked forward to doing it:

*“Because we really use this stuff – especially if we go to the **research**, if you have to go to **medical research** sometimes you have to be able to look at these things... at least be able to know how to read them and to understand what’s going on. I think it’s going to be nice for other people to be able to learn about this stuff, what’s going on.”*

Three pre-med students expressed the need not only to understand physics behind the medical procedures themselves but to be able to explain it to their patients:

*“When I am doctor... hope I will be a doctor... I definitely am going to explain to people the reasoning behind a treatment... because having them understand will make it more **applicable**... and it will make it more likely that they are going to follow it.”*

Often our interviewees also put their answers in a more general context of applicability of what were learned in college classes:

*“When you **apply** physics to a real world and make it **applicable**... that’s when people pay more attention, and they will try to understand it because they realize that **they need to understand this.**”*

Even some non-pre-med students saw the necessity of knowing the nature of medical imaging techniques in their life:

*“I think it’s important to know because if I am visiting my doctor, I think it would be nice to know better what he is doing because he talks about five million words per minute so... It’s always good to understand more especially with what you are working with.”* (This opinion was expressed by a non-science student)

Some students had specific recommendations about the content of the future physics classes for pre-meds:

*“What it comes to a chapter about light, about UV, about electromagnetic waves, you know, the spectrum, then you can mention something, maybe dedicate about a day or lecture to this so the students can understand because I don’t remember I studied anything, I don’t know much about physics. So I think they should incorporate it into the lectures”*

*“It would be much better if we actually **apply** like these X-rays... and sonograms”*

Chemistry classes proved to be more valuable for students than physics classes, and even two pre-med students expressed a wish that in physics classes the teaching physics of medical imaging would be somehow coupled with chemistry:

*“I think it should be after you take **chemistry** and stuff like that because it definitely helps... I think images... bringing them to grouping somehow... similar images that use similar waves... probably you have to do a quick review over wavelengths and stuff like that... because we forget that pretty soon... if you aren’t working with it or seeing every day... I know that I was presented with this information at one time... but I just forget it. If you teach a class you have to do a quick review of that, unless you take it right after your **chemistry**... or physics where they would have seen it... I think a lot more I got from my chemistry class than I got from **general physics**... I remember it more from **chemistry**... Actually we talk about like the principles... what wavelength and all that stuff. What goes behind... how it gets these images may be good. And actually see this stuff, you can go on trips on something or if you guys have X-ray machines around... I think it would help a lot... to see what actually is going on... this way you can get more of a picture... what’s producing what image.”*

Some students recalled that they discussed something in physics classes but nothing specific:

*“I remember discussing it a little bit... but I think there should be more direct relationship... and students will be able to see why... the learning would help them later on.”*

Often students put the topic of medical imaging into the context of real world connections of physics classes in general:

*“I just think that best way to apply things... is that you have a **real world example**... and you can make a quick connection to it... Especially with these, if it was taught with like you are saying with sound and light that would be really good... correlation between these two... and something that is **definitely applicable**... to the subject that you are talking about in class.”*

### **6.3.19 General Attitude**

Often students expressed a great desire to learn about the advanced medical imaging techniques – even after the interviews they asked us to explain how CAT, MRI and PET actually work:

*“These I have known very easily like I said, but CATs, MRIs, stuff like that... I am just not familiar with those – what they do... like how that works at all. It would **definitely be interesting to know... and it’s really useful**. Especially if you are going to medical school.”*

Sometimes students expressed frustration even if they felt enthusiastic during the course of the interview and showed considerable knowledge about the subject.

*“I feel terrible that I don’t remember this stuff.”*

*“I don’t think that I was any useful here... I am sorry, may be you didn’t really want to talk to me...”*

## CHAPTER 7 Results of Teaching Interview

As we described in the previous chapter, initially our interviewed students either did not have any ideas how CAT scans worked or had some vague ideas that it was a separate imaging technique similar to ultrasound or like MRI or PET (about which they again knew almost nothing). They were usually quite surprised that CAT scans used the same X-rays as regular “old-fashioned” roentgenology.

For qualitative assessment purposes we conducted two small discussions comparing the X-ray hand picture with the CT-scan slice picture from our initial set of pictures for the clinical interview.

### 7.1 Students understanding of CAT scans really improves as the result of completion of the activities

We start presenting the results of teaching interviews in a somewhat backward fashion - with the most important conclusion – based on the comparison of the students’ ideas about CAT-scans before and after the teaching interview. It’s the main proof of the effectiveness of teaching materials that can be based on these activities.

#### *7.1.1 Pre-Activity Discussion about X-rays and CAT-scans*

In the pre-activity comparison discussion, which ended each clinical part of our clinical + teaching interview series, when students were asked about the differences between X-ray pictures and CAT-scans, they concentrated more on “what” they see. They either did not have any ideas how these two technologies differ from each other or assumed that the nature of CAT signal is somehow different from the nature of X-rays. Only one student actually knew that CAT-scan machines use X-rays.

The typical answer, given by students was: “*Here we can see only bones... cannot actually see any soft tissues*” or “*Here we can see **bone structure**... cannot get any real decent **tissue information**... we cannot really see **muscles**, how **ligaments** are attached... obviously X-ray images involving **skeletal structure** of the body...*”

This opinion was in some form shared by all but two individual students that participated in the Phase 3 and by six out of eight groups of students that participated in the Phase 4. In the other two groups there was one student, who already knew something about CAT, and one who knew quite a lot, so our lab activity wasn't like a true discovery in a constructivist sense for them, although the students still enjoyed it and did it with enthusiasm.

### ***7.1.2 Post-Activity Discussion about X-rays and CAT-scans***

In the post-activity discussion all our interviewees were already aware that the signals in CAT-scans and X-rays have the same nature, and they concentrated more on “how” different tissues are seen. A typical response about the X-ray picture was: *"We can see how organs interact or are **arranged according to each other**... here we cannot tell for one of the fingers if it's **pushed back** or something... normally you really can't tell..."*

When the same student answered the CAT-scan question, she said: *"You get a different picture from that side... and from this side... here you definitely get more information... different kind of information."* So we can conclude that they have qualitatively understood the idea behind the scanning as the result of completing the activity.

### ***7.1.3 The course of the teaching interview***

When dealing with a task of figuring out what is inside the Lego™ box some students tried to “overtransfer” the ideas from the previous discussions, although the implementation of it wasn't possible at all under the given circumstances: *"So we are using X-ray machines to see what's inside?"* Three students expressed this or a similar idea.

But it was rather just a misunderstanding. When asked what kind of more simple and realistic equipment they would need to figure out the shape of the construction inside the box, they gave, playing the role of a Lego™ physician, very conscious arguments:

*"Like an image... You don't want to open your head... it's silly... I think... that... when we talked about different lights, different colors, about electromagnetic waves to go there... and we can see what comes out I guess. If you can get light... if it's semitransparent we could get light from different reflections... what's coming off... like different refractions... may be we can get an image that way of what's inside... would mean something in there."*

So here we see how a student tries to make a cautious choice among the things that were discussed during the clinical interview stage and makes a successful effort to transfer them appropriately.

Here are typical answers from less talkative students:

*“The light that shines through the... And what else?... Something to receive this light signal, yes?”*

*“So can you just flash the light and look”*

*“Maybe a mirror on the other side? May be the red light would get it... and wherever it meets the object... which I don’t know... the reflection would go back.”*

The answers of almost all other students could be put somewhere in between these two examples.

Only two individual students and two groups of students needed very serious scaffolding, like explaining the properties of semi-transparent red Lego™ bricks, before they were able to come up with the proper pieces of equipment – a light receiver and a light source.

All the individual students except for one and all the groups were able to figure out that we needed to go around the boxes and write down the readings along each of eight lines in two perpendicular directions in order to figure out the shape of the unknown thing inside. And the student who couldn’t come up with this idea by himself, still, like the others, understood this necessity afterwards, and was able to complete the task just as successfully as the other students.

In general, students successfully completed the lab, which gave them the basic understanding of CAT-scans. This conclusion is confirmed both by their own self-reflections and comparative pre-activity and post-activity discussions during our interview.

*“I think it is a good conceptual lab that allows the student to have a hands on approach to see how CT scans work”*

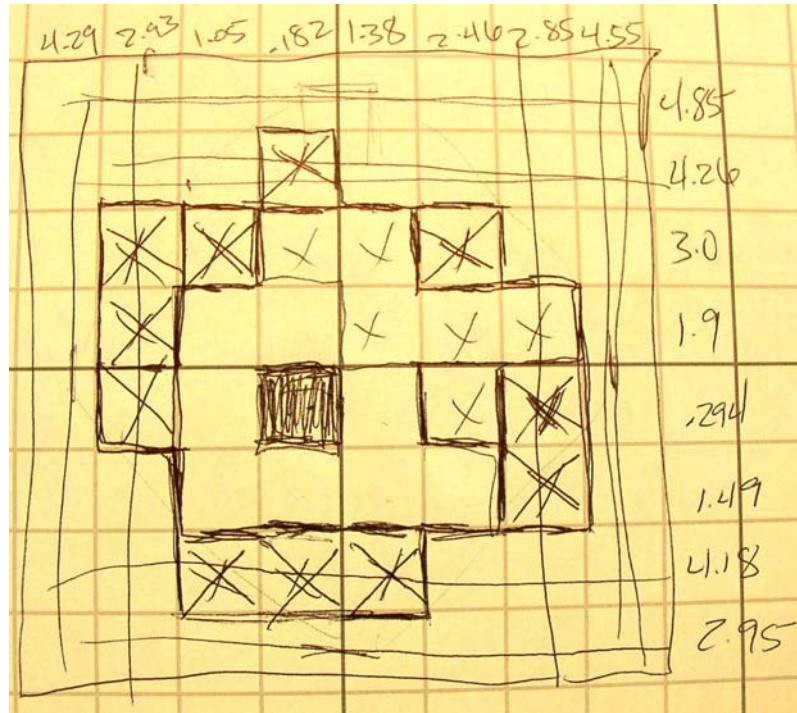


Figure 9: A typical LEGO™ configuration predicted by a student according to light measurements across the closed box

## 7.2 Persistence of the Light Attenuation Linearity Idea

Students properly qualitatively interpreted how the readings of the photovoltmeter depended on the number of bricks along the way of the LED light:

*“In comparison with... I think the more light coming over to this end would give more current... and give the higher voltage reading. So for the ones that have the higher volt readings... the less in the middle... that is absorbing and taking in light... comparing to that have higher or lower readings... I think I said that backwards... I mean high volt readings mean there’s less blocking the light... so there is less in here... and the lower reading means more in there”*

But often the students’ initial assumptions were that the dependence is going to be linear (the simplest and most familiar function to them): *“It’s going to be like a flat...”*



Then, understanding that the voltage cannot go below zero, they tried to accommodate this view to the reality: *“It will stop at some number greater than zero...”* And even further: *“No, it will go to infinity at some level above zero.”*

When prompted to think more deeply about it they understood that the dependence cannot be linear but except for one student during the individual stage and one student in one group during the group stage (Phase 4) the idea of exponential decrease did not come into their minds:

*“The slope between the two points is getting smaller. .. If this is a **nice straight line**, I can calculate a straight line... but I am trying to think on this one... see... I am feeling silly now... I am really not sure how can I calculate it. Like you want me to calculate the equation of this **line?**”*

But even after they were prompted directly to think about exponentiality and having realized that the dependence could not be linear, even the most knowledgeable students had difficulties giving a coherent description of what is happening to the light while it passes through the set of bricks:

*“I would think it would be more like **linear** than **exponential**... if I haven't done any observations or experiments... Because I would think it would eventually stop... like eventually it will not be able to penetrate and to show any voltage through... eventually... .. I would assume it would **go down the same amount every single time**...”*

We think that these students' tendencies of perception of linear and exponential attenuation, although not central to our studies, are very important to understanding the process of image reconstruction and probably can be extended to other topics of physics and mathematics.

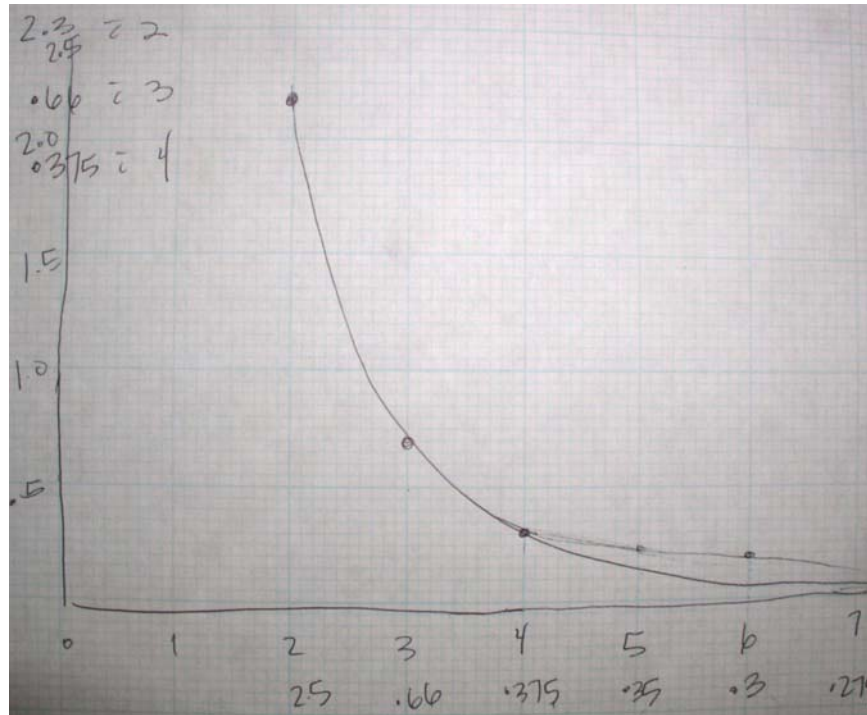


Figure 10: A typical “exponential” graph made by a student after the “linear” prediction

### 7.3 “Like a puzzle”

Trying to figure out the shape of the Lego™ construction inside the box for some students looked like a puzzle, and few times they expressed it directly:

*“I think that I am doing a plain guessing... it’s kind of these weird sudoku puzzles”*

Two times the words “*brain-teaser*” and “*riddle*” were mentioned. We think that although it was not a very popular unprompted response, it can give us insights how to make our teaching module more entertaining (although perception of the lab activity as a game, while being consistent with Jean Piaget constructivist views, also may have some drawbacks, been perceived by students as non-serious, irrelevant or even annoying).

### 7.3 Results of Group Teaching Interviews – Phase 4

Discussing the results of the previous phases of our research we noted that almost all participating students mentioned greater and lower “density” as the reason why some objects are more visible and some are less visible on X-ray pictures. During this group interview stage, this “density explanation” of visibility was just as popular as previously. Here one of the group

members came up with that idea and the others (or the other for two student groups) easily adopted it. Thus, it became the part of their common model. This process occurred not only with the "density" concept. For instance, group discussions enabled students to attribute transverse and longitudinal characteristics to electromagnetic and (ultra)sound waves.

Every group of students also easily recalled that the X-rays are part of the electromagnetic spectrum, and by their common effort all the groups put all the different kinds of electromagnetic waves in the right order. In two cases, when one of the students proposed that X-rays have longer wavelength than visible light, he or she was easily corrected by his/her peers. In the individual interviews it required considerable effort and time to correct such a mistake (asking the questions like "*What other wave characteristics electromagnetic waves have except for wavelength?*") and in a couple of cases such a cueing did not work - the misleading p-prim [diSessa, 1993] "stronger wave - longer wavelength" was too stable. But in the group interviews the students easily corrected this mistake through their discussion. And their active, creative participation in the discussion showed that the proper ideas were triggered by their peers and facilitated the transfer of learning and that students did not just borrow somebody else's opinions and passively agree to them. The groups of students collectively constructed the models of X-rays, reinforcing each other's transfer process.

Below we present few characteristic examples how the various aspects of students' mental models were "fixed" just in the process of their peer interaction.

### ***7.3.1 Fixing the Frequency-Wavelength Confusion***

Here is an example of the typical development of our discussion - among I (interviewer) and A, B, C (three different students) :

*A: "X-rays are of certain wavelength"*

*B: "Yes, they are waves"*

*I: "Are X-ray wavelength shorter or longer than the wavelength of visible light?"*

*A: "Longer"*

*B: "No, they are shorter... Frequency is higher"*

*A: "Oh, yes"*

*C: "I agree."*

*I: "Can you draw how the type of the wave depends on the frequency?"*

C: *“The spectrum?”*

I: *“Yes”*(Together, after a couple of initial mistakes, they put all the parts of the electromagnetic spectrum in right order except for microwaves)

### ***7.3.2 Fixing the Transverse-Longitudinal Confusion***

Another shortened excerpt from the same transcript (discussing the ultrasound picture):

I: *“How are these (sonograms) different from these (X-rays and other EM waves)?”*

B: *“I don’t know.”*

A: *“Sonograms are longitudinal... vibrational, while EM are transverse and not vibrational...”*

B: *“Oh...sound needs a medium to go through and EM doesn’t. EM waves have perpendicular electrical and magnetic components....”*

I: *“And what about sound waves? What do they have?”*

A: *“I don’t know... nothing like these...just waves”*

B: *“They are moving back and forth.”* (Then, draws the picture and tries to wave hands more or less appropriately illustrating how a longitudinal wave moves and how it differs from a transverse wave)

### ***7.3.3 Fixing the Spectrum positions***

Below there is an example of how students help each other to recover the positions of the different parts of the spectrum:

I: *“What kind of spectrum?”*

A: *“The... let’s see... what’s the spectrum... the... I don’t know... it’s called the light spectrum I would say...”*

B: *“Electromagnetic”*

A: *“Yes, I agree”*

I: *“And what other parts does the spectrum include except for X-rays and light (or visible light)”*

A: *“Gamma-rays”*

B: *“Ultraviolet and infrared go there”*

I: *“To what side goes which”*

A: *“Ultraviolet goes here, and infrared here”*

B: *“No, it’s reverse.”*

A: *“Oh, yes.”*

I: *“And what about the other parts of the spectrum?”*

A: *“Radiowaves, microwaves are here”*

B: *“Yes.”*

Finally they put everything in the right order.

At the end of each conversation the students unanimously agreed with the target scientific idea.

In these short transcript pieces we can see examples of peer scaffolding in which students help each other during the discussion, giving each other confidence and triggering proper transfer, building upon each others idea to construct knowledge while the interviewer just had to ask simple questions without extensive (and sometimes quite inventive) cueing, as was necessary during the individual interview stages. The role of the interviewer here is rather diminished to just helping students move from one set of discussion to another.

But in general, while constructing the consensus model required much less input from us, these models were basically built in the same way as in our previous stages. There were no final disagreements among the students, although in a couple of cases less knowledgeable or less confident students really just joined to the opinion of their more convinced partners, and we could not do much here to help them under the existing format. But the majority of students demonstrated that the social interaction with peers help them transfer pieces of knowledge from different sources, build scientific models of X-rays and use them while completing CAT-scan related activity.

The group interaction facilitated both the discussion related to X-rays and the lab activity. The relevant core knowledge of different students overlap the Zones of Proximal Development of their peers [Vygotsky, 1979], creating the common target knowledge which often led to faster conclusions than with cueing and scaffolding from an instructor. Vygotsky also emphasized the fact that language and culture are the main frameworks through which humans experience and understand reality. If a less knowledgeable learner and a more knowledgeable one share similar conceptual schemes - the construction of cognitive structures is easier.

Also, we have to take into account that one of the epistemological beliefs of students (or epistemic mode) about learning physics is that knowledge is propagated [Hammer et al., 2005]. This mode is easily activated in the presence of a physics teacher-interviewer, especially if he takes a very active role.

When students work with peers they look for the alternative ideas in a less-intimidating environment, and this facilitates students reasoning. The other mode of epistemological belief (knowledge is fabricated) is promoted in such cases. Students, rather than just try to recall and/or guess an answer, attempt to construct ideas.

## **7.4 Results of Group Teaching Interviews with Computer Simulation –**

### **Phase 5**

All the groups of students successfully completed the Phase 5 lab with computer simulation like the previous groups did in Phase 4. While it was not easy to tell just from our interview what affected their model construction and understanding of CAT technology more we can say that both activities proved to make an essential contribution to these goals.

In their reflective discussions students explicitly said that a simulation part was more “fast” and “precise”, that it was “more accurate and easier to see the entire progression” of CAT-scanning process without interruption.

*“The computer had much less errors than the Lego activity which made it easier to understand.”*

While the use of Legos<sup>TM</sup> was most helpful to students in gaining a “conceptual understanding”, the hands-on activity gave them “a chance to put the picture together themselves” (again I am using students’ own words).

*“The Lego experiment allowed us to visually see how a signal is used to help reconstruct an image.”*

*“It worked better in actually using the photometer, it explained what exactly is being done by the computer to find the image.”*

*“We had the chance to put the picture together instead of watching it be created for us.”*

Students proposed different very cognizant changes – like using simpler easier shapes for the objects inside the box, or to make better alignment of the light receiver and the light source.

In general they felt that the lab was very informative and useful to them:

*“The lab has a very unintimidating feel to what seemed like at first a very complex topic.”*

*“Very thought- provoking. Something intellectually challenging. I would love to have done this in one of my physics classes.”*

*“It also helped me to voice my opinion and find alternatives to getting better results.”*

*“Comparing our hypotheses to the actual shape of the object was most helpful in understanding of image reconstruction.”*

## **7.5 Effect of Group Size on Learning**

In the group teaching interviews during Phases 4-5 our students worked in the groups of two or three. One of the rationales for dividing students in two different sized groups was to see the difference in the group dynamics. But since the sample size was comparatively small we cannot formulate any generalization from the results. For instance, we cannot argue which of the groups was more effective in learning, although we will give some thoughts about the future research in the next, concluding, chapter.

## **7.6 General Students’ Attitude toward The Activities**

### **7.6.1 Successes**

We also have to emphasize how enjoyable the lab experience was for the students. Although their enthusiasm during the activities was not directly connected with our research goals, it definitely helped them finish the task successfully. So some of their words are worth being put here:

*“I think it’s really cool... interesting and... I mean... it’s one of the most interesting physics kind of labs... kinds of thing I ever done. It really gives the idea of what’s going on in the computer... like CAT scans... still kind of elusive how do they get this formula... to get that nice picture that you see on there... but I see more of the basics of what is going on... I can see how eventually someone could derive that... and then see that graph... and the ratios... I think that it really was cool... it’s cool. And it’s just playing with Legos.”*

*“I really liked when you lined them up – especially when I broke them down with the ratios and everything... I really liked that... I liked the block thing... like if I did it on my own... may be it’s my accuracy... may be something in it... a little bit different... and this kind of irritates me... because some people grade hard and they want you to be perfect you know... that would be frustrating... but overall you get the point... you can see the trends... it’s somewhat hard to compare across the board because there are slight differences. But I think it really did show me what was going on and it was kind of fun – try to guess and to see how close you were. It’s nice when you like – yeah, I got one. I like it and enjoyed the project. I don’t even know how long it took.”*

*“You kept me thinking and occupied the whole hour and I didn’t really feel the press of time... because I found it interesting.”*

Students made very thoughtful suggestions on how the lab can be changed:

*“Make a procedure of obtaining light reading more accurate, maybe there was too much internal reflection or something else that caused us to get wrong readings.”*

### **7.6.2 Problems**

As for the problems that we encountered during the lesson, the students often somewhat resisted the learning cycle format, which was unusual to them:

*“This lab was pretty good, maybe a little more explanation on what we were trying to do was needed. It was a little difficult to know what we were expected to accomplish.”*

*“The Lego part was frustrating because I didn’t know entirely what I was doing but after using the computer it made sense.”*



## CHAPTER 8 Conclusions and Implications

### 8.1 Answering The Research Questions

The research questions posed by us before we undertook this study, or in the process of it, were the following:

“From which sources do students transfer their learning about X-rays?”

“How do they elicit and construct their models of X-rays?”

“Which factors affect their dynamic model construction and facilitate transfer during the interview?”

“How group and individual students’ learning behavior are compared in our settings?”

“Are the proposed activities pedagogically effective?”

Based on the findings of our research, we can say that we are able to answer these questions.

#### ***8.1.1 “From which sources do students transfer their learning about X-rays?”***

As we already discussed in Chapter 6 students transfer their ideas about X-rays from various sources – among them the most important are physics classes, personal experience (virtually for all of them, often including real work with the equipment for pre-med students) and mass media (many referred to TV broadcasts explicitly). The high-school physics classes, more conceptual and qualitative, often gave more to students in terms of knowledge of X-rays than more advanced algebra and calculus-based college classes, although the latter also significantly contributed to their model building.

#### ***8.1.2 “How do they elicit and construct their models of X-rays?”***

Before students start to construct their models of X-rays, they should have switched from the “knowledge is propagated” to the mode “knowledge is fabricated”. Although initially students were not confident of their physics knowledge related to X-rays, with careful constructivist cueing from an interviewer (or/and interaction with peers in group teaching interviewees) they were able to successfully build these mental models.

The first phases of our study based on clinical semi-structured interviews with college students revealed that pre-meds' (and some other) majors' ideas about X-rays can be described as models, although these models are rarely coherent and not very stable. They depended on our follow-up questions and cues, and sometimes just on the order of questions. Even being accompanied by broader knowledge (e.g. Engineering students) and greater interest (e.g. pre-med students) these models often remain incoherent. But in the interview process, through Socratic dialogues and careful leading, students often successfully put together the pieces of knowledge transferred from their physics classes and combine them with other pieces of information, creating some more or less scientific knowledge right on the spot.

We definitely should use this student readiness and ability in our classrooms and, for instance, can let them discuss X-rays in small groups at the beginning of class using cueing similar to which we provided.

### ***8.1.3 “Which factors affect their dynamic model construction and facilitate transfer during the interview?”***

This question is naturally connected to the previous one, and it was answered by all parts of our research – both clinical and teaching interviews. From the teaching interview with the Lego™ activity we saw that students successfully transferred their learning of optics to a practical image reconstruction problem. In addition, our results show, that once the students recognized this solution, they were able to transfer learning about basic X-rays to image reconstruction in X-ray based CT-scans.

Overall, we have investigated transfer of learning when combined with scaffolding activities in a learning-teaching situation. We see that students will transfer ideas from a large number of different sources to address the application of physics to a situation which is new to them. This transfer involves pieces of knowledge, which are then brought together with the help of appropriate hands-on activities and scaffolding questions.

It has not been a surprise that our findings confirmed that the non-traditional instructional strategies, where students are active in the different stages of teaching-learning activities, work much better than more traditional ones. But for pre-med students, who often don't understand the relevance of physics and its importance for their future profession, as pointed out in Chapter 1, we think it is much more important than for many other pre-professionals. Also we advise

physics instructors to encourage group interaction to promote transfer of learning. New teaching materials in modern physics which use hands-on activities and computer technologies could help the students change their conceptions significantly in many contexts.

#### ***8.1.4 “How group and individual students’ learning behavior are compared in our settings?”***

The study gave our students social contexts while learning with the help of an instructor or their peers. Students got the opportunity to learn in their Zone of Proximal Development (ZPD) while interacting with the interviewer-instructor and peers.

We observed that our interviewees learn considerably better when they worked with more knowledgeable others. Quite a few times they were very successful in breaking peers wrong associations and building appropriate ones.

The extremely good influence of group interaction on the students’ model building and completing the lab task inspired us to try to design a peer instruction [Mazur, 1997] piece in small studio-like groups, where students will answer questions and discuss them among themselves before any formal instruction starts.

#### ***8.1.5 “Are the proposed activities pedagogically effective?”***

The last phase of our research endeavor proved that hands-on activities, even while teaching such computerized medical imaging technology like CAT scans, can still find their deserved place in our curriculums, especially when coupled and integrated with computer simulations.

Even when students profess (or protest) that they know nothing about a topic, they can be helped to construct new information from their existing intellectual resources, even about relatively complex applications such as medical imaging.

So we can convincingly say that the proposed teaching materials will be an effective tool that is worth further studies, development and testing. The learning progress was confirmed both by our assessment during qualitative discussions and by students’ own self-reflections. Our interviewees clearly understood now that neither density nor any other local characteristic could be associated with any detail on regular two-dimensional X-ray pictures. There we can see only fuzzy integral effects of X-rays and interaction with various adjacent tissues or materials. Only

more comprehensive three-dimensional imaging procedures such as the (just learned) CAT scans can do such a comprehensive job of “seeing” virtually of all the points inside a studied object.

## **8.2 This work in a context of physics education research and physics teaching**

We think that the results of our work can prove useful not only for the purposes of medical imaging teaching (or for more general goals outlined in the MMMM project) but also for other areas of physics education research and physics teaching. We can actively engage students from many pre-professional areas. We saw from our teaching interview series that students can actively transfer ideas from various sources, interacting with each other.

Hands-on lab materials incite students interest and help them to switch to “knowledge is fabricated” epistemic mode. We think that historical accounts are also very valuable in helping students to build mental models together with the Learning Cycle format and Socratic dialog.

In the same way we can use appropriate scaffolding to teach other topics, with which students are not familiar - or may think that they are not familiar – but later may prove otherwise.

## **8.3 Recommendations and propositions for further research**

Quite a few new investigable questions could be asked based on our findings.

One of the possible directions for future research, as we already mentioned in the previous chapter, is to look at the optimum number of students in a group for the most effective learning of physics of medical imaging. Probably this question can be address in the action research format, in “real” teaching settings with 2, 3 or more people in each group.

We can also vary the time that is given to students on the tasks, to put more focus on either hands-on activities or computer simulation, More research may be undertaken to explore them further, were we can weigh the pros and cons of both components further, and we can pay more attention to sequencing and find the best placement of the computer simulation in the CAT-scan learning module.

We can look further into successive stages of the Karplus and Hestenes’ Modeling Cycle and see how student learning and transfer enhanced using it.

We can look deeper into the “density idea” and see whether it has “mechanistic” macroscopic-like foundations, meaning that X-rays is a substance that less easily goes through more densely packed structures or whether something deeper can be hidden behind this.

The other area of our future research may be an investigation of student learning with the help of peers of different levels. We can explore whether a particular student learns better with peers with more similar (homogenous) or less similar (heterogeneous) ZPD.

Another direction for future research may be one of the adjacent areas of medical imaging - ultrasound, a topic that was discussed extensively in our studies, and also therapeutic applications of X-rays.

The interview data, which have been collected in this study, also of course can be analyzed further. During our analysis we focused only on the material that looked relevant to our research questions, but, for instance, we can concentrate more on students' epistemic mode, on their motivation, etc., which also could be an important and fascinating aspect to understand the transfer of leaning.

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# Appendix A

## KANSAS STATE UNIVERSITY INFORMED CONSENT TEMPLATE

**PROJECT TITLE:** Modern Miracle Medical Machines

**PRINCIPAL INVESTIGATOR: CO-INVESTIGATOR(S):** Dean Zollman (PI)  
Spartak Kalita (Co-Investigator)

**CONTACT AND PHONE FOR ANY PROBLEMS/QUESTIONS:** 785-

**IRB CHAIR CONTACT/PHONE INFORMATION:**

Clive Fullagar, Chair of Committee on Research involving Human Subjects  
1 Fairchild Kansas State University,  
Manhattan KS, 66506, (785) 532-3224

Jerry Jaax, Associate Vice Provost for Research Compliance  
1 Fairchild Kansas State University,  
Manhattan KS, 66506, (785) 532-3224

**SPONSOR OF PROJECT:** National Science Foundation

**PURPOSE OF THE RESEARCH:** To investigate students' understanding of conceptions in physics, and how it depends upon the context (situation) in which it is presented,

**PROCEDURES OR METHODS TO BE USED:** Interviews, written open-ended and multiple choice questions



**ALTERNATIVE PROCEDURES OR TREATMENTS, IF ANY, THAT MIGHT BE ADVANTAGEOUS TO SUBJECT:**

None

**LENGTH OF STUDY:** 2 meetings ( 30 minutes - 1 hour)

**RISKS ANTICIPATED:** No known risks

**BENEFITS ANTICIPATED:** Deeper understanding of physical phenomena

**CONFIDENTIALITY:** The student's performance and/or statements during interview and in survey will not be disclosed with students' name or any identifying feature.

**PARENTAL APPROVAL FOR MINORS:** Not Applicable

**PARTICIPATION:** Voluntary

I understand this project is for research and that my participation is completely voluntary, and that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I also understand that my signature below indicates that I have read this consent form and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

Participant Name: \_\_\_\_\_

Participant Signature: \_\_\_\_\_

Date: \_\_\_\_\_

## **Appendix B**

### **First Interview Protocol**

**Have you seen such pictures before? Where? Under what circumstances? What do you see in these pictures?**

**Here is the first ever inside-body picture, capturing the Roentgen wife's hand. Can you propose some explanation why you see the bones but don't see any other hand tissues including the skin? Do you have any ideas about why a black spot appears around one of the fingers?**

**Can you see something like this with your naked eye? How would you explain this?**

**Have you ever undergone the X-ray procedure? If not do you know somebody who has? Can you recall some details? Do you remember any other medical procedures that make visible what's inside your body?**

**Do you remember anything about X-rays from your physics classes? If so what is it?**

**How do you think X-rays are similar to or different from visible light? From radio waves? From sound (or ultrasound)? From a flux of small solid particles?**

**(Can you tell me more about the nature of light, radio waves and sound?)**

## **Appendix C**

### **Interview Protocol - Phases 2-3**

**Can you group these pictures somehow? What is different and what is similar between (among) these groups?**

**Here is the first ever inside-body picture, capturing the Roentgen wife's hand. Can you propose some explanation why you see the bones but don't see any other hand tissues including the skin? Do you have any ideas about why a black spot appears around one of the fingers?**

**Can you see something like this with your naked eye? How would you explain this?**

**Have you ever undergone the X-ray procedure? If not do you know somebody who has? Can you recall some details? Do you remember any other medical procedures that make visible what's inside your body?**

**Do you remember anything about X-rays from your physics classes? If so what is it?**

**What other things are similar to X-rays?**

**What other imaging techniques do you know?**

**How they are different from X-rays and similar to them?**

**Why do we need them, why X-rays aren't enough? What are the limitations of X-rays?**

**What makes some parts of the picture(s) here darker and some of them – brighter than the others?**

## **Appendix D**

### **Preliminary discussion (clinical interview part)**

**Can you group the pictures?**

**How these pictures are different from and similar to each other?**

**Let's concentrate on X-rays for a while. Where and what have you ever heard about them?**

**Why we can see here what we cannot see with our naked eye?**

**Have you undergone this procedure? Can you recall some details?**

**What other things are similar to X-rays?**

**What other imaging techniques do you know?**

**How they are different from X-rays and similar to them?**

**Why do we need them, why X-rays aren't enough? What are the limitations of X-rays?**

**What makes some parts of the picture(s) here darker and some of them – brighter than the others?**

### ***Pre-Activity Assessment Discussion***

**What kind of information about human inner structure we can get using X-rays?**

**How is it different from what we can get using other imaging techniques?**

**How are these (CAT-scans, not calling them by the name) pictures are different from these (X-rays)? How are they similar?**

### **Main lab (teaching interview part)**

**Here is an analogy that uses Legos. You see the two setups (boxes). The walls of both are made up of red semi-transparent Lego bricks; they covered by white non-transparent pieces of paper (and marked "1" and "2"). Also objects which are hidden**

inside these boxes are constructed out of the same semi-transparent bricks as the walls. Thus, you have a situation which is analogous to the one that a physician faces – something is inside; you know a little about it but you cannot see it directly.

Your job is to play the role of a Lego physician and determine the shape of the “organ” inside the Setup 1 that might be disfigured and “sick”. (For simplicity the height of these objects is the same as the height of the walls, and their edges continue the lines that originate between the bricks of the walls).

There could be several ways to address this problem. One of them uses a source of light that will pass through the Legos and a photovoltmeter which can measure the amount of light that passes through the bricks. How might you use them to perform our task?

Now open Setup 2. Here you will see a similar structure (but of course of a different shape) to the one that is inside Setup 1. So now you have the freedom of closing and opening the Setup 2 at any time. How does it facilitate your task?

After closing the lid, follow your procedure with the Setup 2. Record the corresponding readings. Explain how these readings can help you describe what is in Setup 1

What are the limitations of this description?

Now complete a similar experiment for Setup 1 and record the results.

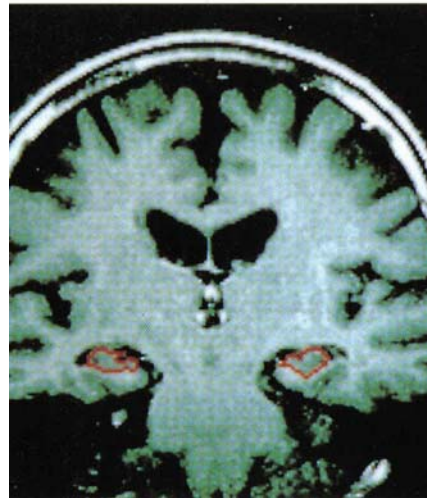
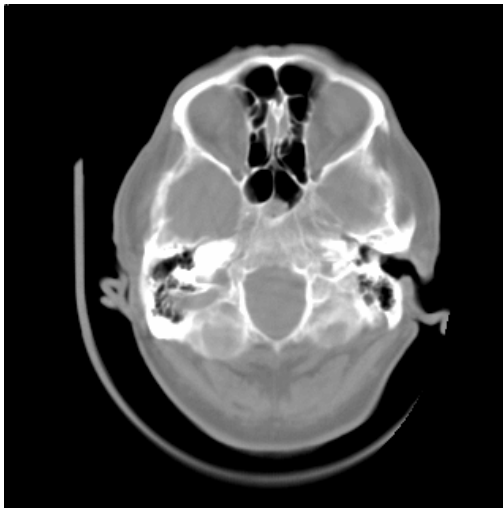
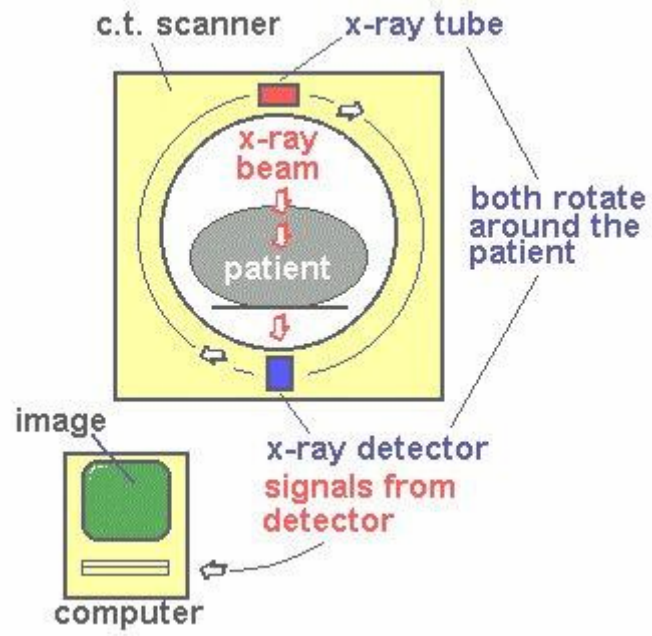
Using the results for Setup 2 as a guide, do the best job that you can to describe what is inside Setup 1. Sketch the object inside and explain your reasoning.

Now return to the Setup 1 – and make the final prediction. Open the box. Compare your prediction with the real thing.

**If your predictions weren't exactly right - how would you explain the discrepancy? In the lab terms - what are the sources of errors? Can we get rid of them? (If you got it right – were do you think we could easily make a mistake?)**

**In this lab we reconstructed the shape of the hidden object by using non-destructive optical methods. Real CT scanning and data-processing procedures are more elaborate, and they use different ranges of electromagnetic waves (like X-rays). However, the idea is the same – we send “signals” into a human body from every direction. We collect data on the signal that emerges and then use that information to construct the best image that we can of the internal organs. The process is called image reconstruction. Some CT-related pictures are shown below:**





### *Post-Activity Assessment Discussion*

**Let's return to some of the question that we discussed before the lab.**

**What makes some parts of the picture here darker and some of them – brighter than the others?**

**Why do we need CAT-scans? Why aren't X-rays enough? What are the limitations of X-rays? How CAT scans allow us to go beyond these limitations?**

**What kind of information about human inner structure can we get using X-rays? How is it different from what we can get using CAT scans?**

**How are these (CAT - scans) pictures different from these (X-rays)?**



## **Appendix E**

### **Preliminary discussion (clinical interview part)**

**Can you group the pictures?**

**How these pictures are different from and similar to each other?**

**Let's concentrate on X-rays for a while. Where and what have you ever heard about them?**

**Why we can see here what we cannot see with our naked eye?**

**Have you undergone this procedure? Can you recall some details?**

**What other things are similar to X-rays?**

**What other imaging techniques do you know?**

**How they are different from X-rays and similar to them?**

**Why do we need them, why X-rays aren't enough? What are the limitations of X-rays?**

**What makes some parts of the picture(s) here darker and some of them – brighter than the others?**

### ***Pre-Activity Assessment Discussion***

**What kind of information about human inner structure we can get using X-rays?**

**How is it different from what we can get using other imaging techniques?**

**How are these (CAT-scans, not calling them by the name) pictures are different from these (X-rays)? How are they similar?**

### **Main lab (teaching interview part)**

**Here is an analogy that uses Legos. You see the two setups (boxes). The walls of both are made up of red semi-transparent Lego bricks; they covered by white non-transparent pieces of paper (and marked "1" and "2"). Also objects which are hidden**

inside these boxes are constructed out of the same semi-transparent bricks as the walls. Thus, you have a situation which is analogous to the one that a physician faces – something is inside; you know a little about it but you cannot see it directly.

Your job is to play the role of a Lego physician and determine the shape of the “organ” inside the Setup 1 that might be disfigured and “sick”. (For simplicity the height of these objects is the same as the height of the walls, and their edges continue the lines that originate between the bricks of the walls).

There could be several ways to address this problem. One of them uses a source of light that will pass through the Legos and a photovoltmeter which can measure the amount of light that passes through the bricks. How might you use them to perform our task?

Now open Setup 2. Here you will see a similar structure (but of course of a different shape) to the one that is inside Setup 1. So now you have the freedom of closing and opening the Setup 2 at any time. How does it facilitate your task?

After closing the lid, follow your procedure with the Setup 2. Record the corresponding readings. Explain how these readings can help you describe what is in Setup 1

What are the limitations of this description?

Now complete a similar experiment for Setup 1 and record the results.

Using the results for Setup 2 as a guide, do the best job that you can to describe what is inside Setup 1. Sketch the object inside and explain your reasoning.

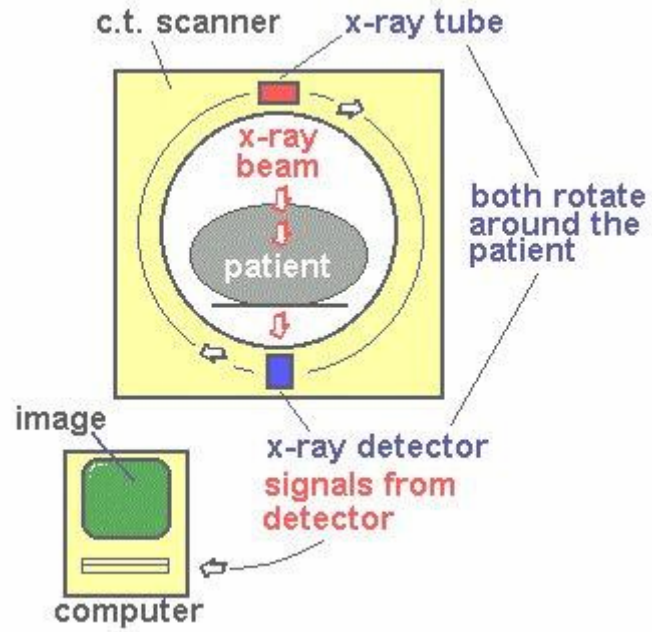
Now return to the Setup 1 – and make the final prediction. Open the box. Compare your prediction with the real thing.

**If your predictions weren't exactly right - how would you explain the discrepancy? In the lab terms - what are the sources of errors? Can we get rid of them? (If you got it right – were do you think we could easily make a mistake?)**

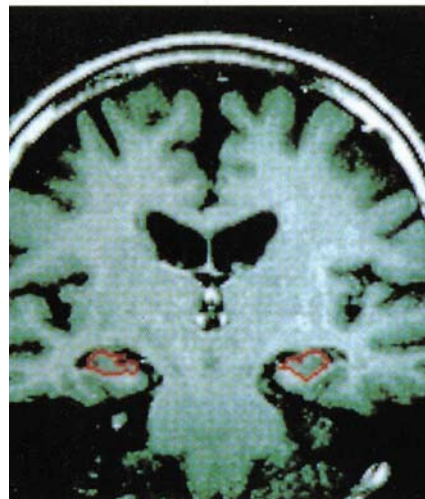
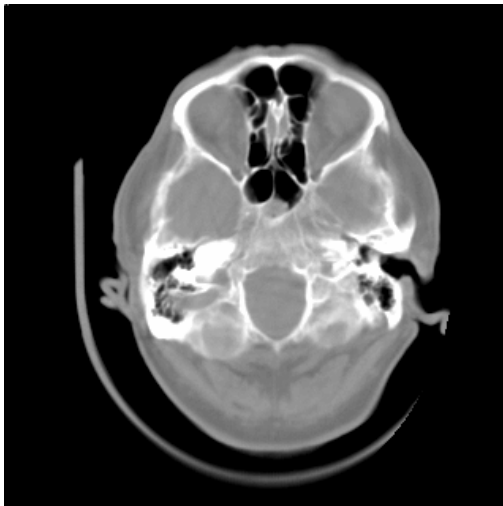
**Now please take a look at this movie. What do you think is happening here? Do you see any similarities with what we have just done?**

**In this lab we reconstructed the shape of the hidden object by using non-destructive optical methods. Real CT scanning and data-processing procedures are more elaborate, and they use different ranges of electromagnetic waves (like X-rays). However, the idea is the same – we send “signals” into a human body from every direction. We collect data on the signal that emerges and then use that information to construct the best image that we can of the internal organs. The process is called image reconstruction. Some CT-related pictures are shown below:**





Now play with the CAT-simulation. Which parameters we should use to emulate our LEGO activity as closely as possible? How do changing these parameters affect the resulting image?



### *Post-Activity Assessment Discussion*

**Let's return to some of the question that we discussed before the lab.**

**What makes some parts of the picture here darker and some of them – brighter than the others?**

**Why do we need CAT-scans? Why aren't X-rays enough? What are the limitations of X-rays? How CAT scans allow us to go beyond these limitations?**

**What kind of information about human inner structure can we get using X-rays? How is it different from what we can get using CAT scans?**

**How are these (CAT - scans) pictures different from these (X-rays)?**

## **Appendix F**

### **Post-Lab Questionnaire for Phases 3-4**

**Do you feel that you now have a basic understanding of image reconstruction?**

**Which part of the lab was most helpful in gaining that understanding?**

**What would you change in this lab? Explain why you would like it changed.**

**What is your general opinion about the lab?**

### **Post-Lab Questionnaire for Phase 5**

**Do you feel that you now have a basic understanding of image reconstruction?**

**Which part of the lab was most helpful in gaining that understanding?**

**Where do you think the hands-on LEGO activity worked better then the computer simulation?**

**Where do you think the computer simulation worked better then the LEGO activity?**

**What would you change in this lab? Explain why you would like it changed.**

**What is your general opinion about the lab?**

