TRANSFER OF LEARNING WITH AN APPLICATION TO THE PHYSICS OF POSITRON EMISSION TOMOGRAPHY

by

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B.S., Tribhuvan University, Nepal, 1992
M.S., Tribhuvan University, Nepal, 1994
M.S., Kansas State University, 2005

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 Science

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

Abstract

A series of teaching activities using physical models was developed to present some portions of physics of Positron Emission Tomography (PET) and investigate students' understanding and transfer of learning in physics to a medical technology. A teaching interview protocol consistent with a qualitative research methodology was developed and administered to the students enrolled in an algebra-based introductory level physics course. 16 students participated in individual interviews and another 21 students participated in the group sessions. The major objectives of the teaching interviews were to investigate students' transfer of physics learning from their prior experiences to the provided physical models, from one model to the other and from the models to the PET problems.

The study adapted phenomenological research methodology in analyzing students' use of cognitive resources and cognitive strategies during knowledge construction and reconstruction. A resource based transfer model framed under the cognitive theory of learning and consistent with contemporary views of transfer was used to describe the transfer of physics learning.

Results of the study indicated both appropriate and inappropriate use of the students' prior conceptual resources in novel contexts. Scaffolding and questioning were found to be effective in activating appropriate and suppressing the inappropriate resources. The physical models used as analogies were found useful in transferring physics learning to understand image construction in PET. Positive transfer was possible when the models were introduced in an appropriate sequence. The results of the study indicate the occurrence of three types of non-scaffolded transfer – spontaneous, semi spontaneous and non-spontaneous. The research found connections between sequencing of hints and phrasing of information in activating students' different conceptual resources. A qualitative investigation based on Vygotsky's Zone of Proximal Development (ZPD) has been completed in two contexts – one involving an instructor and the other involving peers. Significant expansion of the students' ZPD occurred through peer interaction.

The results indicate that the appropriate sequencing of learning activities and group interactions can promote learning. Additional research in transfer of physics learning from macroscopic phenomena to microscopic phenomena are warranted by the conclusions of this work.

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Dedication

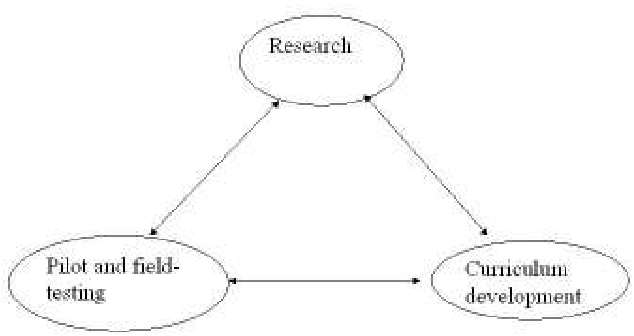
I dedicate this dissertation to my parents, wife and children.

CHAPTER 1 - Introduction

For the past three decades physics education research has made many contributions to physics community in the areas of teaching and learning (McDermott & Redish, 1999). Investigation of students' difficulties in physics learning is the main interest of such efforts. The ultimate goal of physics education research is to develop pedagogical techniques to help improve students' success through curriculum and instruction. In order to achieve the goal mainly two kinds of studies are done. The first one involves the investigation of learning difficulties that the students bring from their prior experiences or prior learning in their classrooms. The second one focuses on the investigation of appropriate instructional interventions to help students learn the scientific skills. The investigation of the former type enables education researchers to think of varieties of learning environments and the latter one helps them to identify the suitable kind of teaching interventions for a particular context.

Figure 1.1 General Interest of Physics Education Research

(Adapted from University of Washington Department of Physics)



In this study, I have focused on both of these aspects of physics education research. I have carried out a study to investigate students understanding in some of the physics ideas. On the other hand, my research design was created in such a way that I could study the dynamics of students' learning processes. In other words, this study has allowed me to understand two aspects: what students already know and what affects their learning process.

Student understanding and learning physics in the context of positron emission tomography was the focus of the study. In order to achieve the research goal, I undertook several steps. The first step in the effort was to isolate key physics ideas of positron emission tomography. The second intent was to identify learning difficulties of students in some of the physics processes involved in positron emission tomography. Another aim was to identify instructional challenges and successes within the area, and situate the results of the study into the relevant physics education research literature. The ultimate goal was to provide both instructors and curriculum designers with a valuable resource through the findings of the research.

In this chapter of the dissertation, I present the factors that motivated me to undertake this quest. I will then describe the bigger project and goals upon which this research is based. Positron emission tomography, which is the main context of the study, will be presented in brief. Some of the influencing frameworks used in the study will be presented in order to situate the study in the bigger frame of discovery. The road map of the dissertation will be discussed near the end of the chapter.

1.1 Motivation of the Study

Contemporary physics is hardly taught in high school. It is introduced to introductory level college students but is regarded as a challenge to teach them successfully. Educators attribute this challenge to the students' limited physics and mathematics backgrounds. However, discussions of such physics ideas make a positive influence on the students' perception of physics and their general interest in physics, provided the emphasis is given on the practical applications. In recent years, development of activity-based instructional units to introduce basic quantum principles to high school and introductory level college students has drawn interest of physics educators and education researchers (Zollman *et al.*, 2002).

The main motivation of this research project is a belief that contemporary physics or modern physics can be taught successfully to that audience. But several measures need to be taken to achieve this goal. One obvious measure is that when these topics are taught the instructional materials must be well-designed, including hands-on experiences or visualizations. As a second measure students should be provided with motivating learning contexts. Yet another measure is that the material difficulty should be of an appropriate level.

There is some evidence that quantum mechanics can be taught to even high school students if emphasis is given to simple experiments, hand-on activities and visualizations rather than focusing on complicated mathematics (Zollman et al., 2002). Research shows that most people learn best through informal, contextual experiences (Gardner, 1983). The creation of learning contexts that they are interested in or that they are familiar with can help them to learn novel ideas through motivation (Wierstra & Wubbels, 1994). It is a well-established view from cognitive psychology that motivation interacts with learning. It is also very crucial to consider how to present such concepts to those audiences. Discussing modern physics in too much detail or on too high level that demand a high cognitive load might have the opposite effect. The materials therefore should be located at an appropriate cognitive level of the students (Yeo *et al.*, 2004). This requires identification of appropriate topics, extent and level of discussion. Appropriate teaching activities have to be identified and developed in close collaboration between teachers and researchers. A careful assessment through research improves the effectiveness of the materials and the student success.

Identification of the suitable learning context is one of the big challenges. Students should be familiar with the learning context through everyday experiences. As pointed out by cognitive psychologists, learning occurs only when learners process new information in such a way that they can find the meaning within their frame of reference (Prawat, 1996). The creation of meaning is possible only if learners can associate the new information with their current environment. A learner therefore searches for the relationships that make some sense and also appear useful.

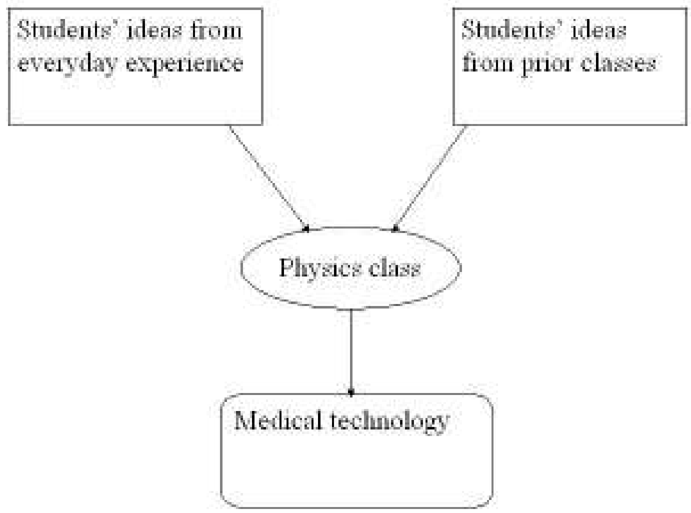
Introductory level college students are often thrilled about advent of modern technology and industry. Contrary to this, they often think that physics is not relevant in their everyday lives. This leaves us in a strange circumstance because students are not making connections between physics and technology. Providing examples of modern technologies as learning contexts for physics shows the relevance of physics in their everyday life. In this way, college students can be motivated to learn physics. Modern medical technology is one of the exciting fields that can serve this purpose. Contemporary medical diagnosis and treatment procedures, which involve both traditional and contemporary physics ideas, require understanding of underlying physics knowledge to understand the process. This would suggest that medical application is a well-suited example of context for introductory level physics courses. The introduction of contexts of medical technology in physics courses not only motivates students pursuing medical field but also general audiences enrolled in physics course.

The research effort presented in this dissertation aims to address the several issues raised in the preceding paragraphs. Exposure of the students to modern physics and its technological applications in classroom instruction can contribute in promoting the general interest of the students in physics. Development of the simple hands-on activities and visualizations to enable the students to learn a wide range of physics ideas including modern physics concepts has been the main interest of the effort. The developed activities presenting some portions of physics of the medical imaging techniques provide the learning context of physics. Another interest within this effort is the evaluation of the activities through research. Attention is given to make sure the activities do not demand a higher cognitive load than students' knowledge level. Research reveals strengths and weaknesses of the projects, in order to carefully adjust the material and the ways of presentation to the target group. The most difficult, but perhaps most rewarding, effort is to implement the exciting field of contemporary physics as an application part in the curriculum for introductory level physics courses.

1.2 Modern Miracle Medical Machines (MMMM) Project

Many of the medical diagnosis and treatment procedures involve the application of a wide range of physics ideas involving modern physics concepts. For example, to understand technology of Positron Emission Tomography (PET) students should have knowledge of nuclear and quantum physics. Students before going to medical school complete the four years of undergraduate study and most of them take the biological and human science. These students also enroll in a two-semester algebra-based physics course (pre-med course). Unfortunately, this is the only physics course that they take during their undergraduate study and medical school. Most of the current pre-med physics courses do not give much emphasis to the application of physics in medical contexts. Some of the textbooks mention medical application as an example near the end of the chapter, but instructors sometime do not even introduce that part in the classroom. Homework and exam problems do not often include such examples. As a result, these students do not get an opportunity to see the relevance of physics in everyday life contexts or professional life. This leads to the situation where the medical students cannot make connections between their physics learning and their professions when they become physicians.

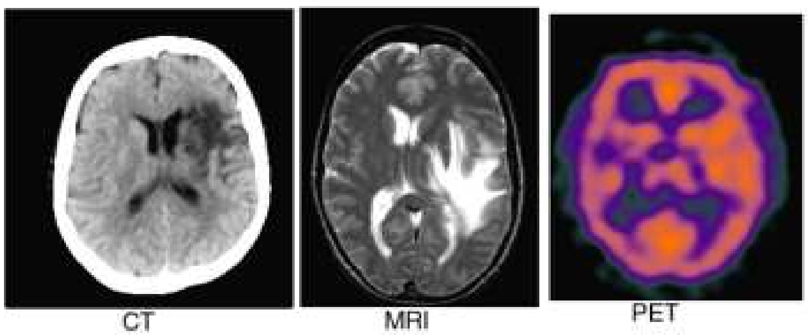
Figure 1.2: Research Focus of the MMMM Project



In order to address these issues a project named modern miracle medical machines (MMMM) has been undertaken (Zollman, 2004). It is a NSF funded project with the goal to design research-based instructional activities for pre-medical physics course. This project, which builds on the Visual Quantum Mechanics (Zollman, 1995), involves a two stage process. During the first stage of the effort investigation of the students' ideas, learning process and learning difficulties in physics concepts related to medical technologies are done. The overview of research in this project is depicted in Figure 1.2. Two interview methods are used to accomplish the first stage of the effort. Traditional clinical interviews are used to investigate what students know and how they use their knowledge of physics to understand medical diagnostic tools. A theoretical framework of the transfer of learning is used to understand student responses. The results of these investigations are then used in the second stage while developing interactive instructional materials. Teaching interviews are done as the second interview method where students work in small groups of two or three to learn from the teaching activities and with their peers. The role of the researcher in the teaching interview is that of facilitator of learning.

The overall intent of this project is to change part of the current pre-med physics courses. However, it does not aim to make the complete revision in the existing pre-med physics course structure. Different activities will be introduced in the relevant topics as application problems in the existing curricula. Students apply their physics learning in the context of medical application. Emphasis is given to use such type of problems not only during classroom but also in homework and exams. Students are expected to learn the physics behind the medical techniques not the medical aspects from the activities.

Figure 1.3: Different Areas of Interest within MMMM Project



The areas under this research projects are X-ray, CAT scan, MRI and PET scan as imaging techniques. Additional undergoing research areas such as the human eye and LASIK surgery are included in the project as modern medical treatment procedures. The research presented in this dissertation focuses on study of students learning of positron emission tomography (PET) and teaching material development on that topic.

1.3 Positron Emission Tomography (PET)

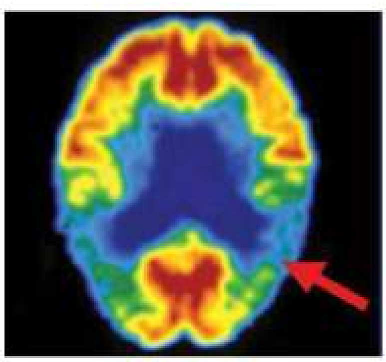
Conduction of research on student ideas and learning and development of teaching materials related to physics of PET is one of the major parts of the *MMMM* project. The effort within the area of PET has used a multi-methodological research approach. It uses several contemporary theoretical frameworks in the field of education and psychology. The research methodologies and frameworks are employed to develop a series of physics teaching activities relevant to some portions of PET based on the findings of students' prior experiences and learning transfer.

The details of the PET procedure and relevant physics ideas will be described in Chapter 2. This section briefly introduces PET as an imaging tool to provide a general idea about it. The instructional approach will also be introduced in this section.

PET has been used as a medical imaging technique for few decades. It allows physicians to measure the detail of the functioning of different parts of organs or tissue. The measurement is made possible by imaging biochemical reactions and physiological functions. The technique produces a scan by the measurement of concentrations of radioactive chemicals that are partially metabolized in the body region of interest. A PET scan is different from other imaging techniques such as X-ray, CT scan and MRI in the sense that the former technique gives information about how the tissue is functioning whereas the later techniques give information about the structure of the tissue. PET is therefore regarded as a functional imaging technique while the others are called structural imaging techniques. Due to this reason, PET scans can be more beneficial as compared to the rest of the structural imaging techniques to identify early stage of diseases. However, a PET scan alone sometimes may not be able to pinpoint the exact location of the abnormality. That is why physicians suggest doing structural imaging along with the PET scan. The scan is not only to diagnose the illness but also informs the physicians about other organ activities. That is why it is widely used in cognitive research (Conway *et al.*, 1999) while studying the relationship between cognitive performance and cerebral events and structures. Recently, scientists have designed a technique that combines PET with MRI.

Figure 1.4: PET Scan Showing Alzheimer

(Source: http://faculty.ccri.edu/kamontgomery/PET%20SCAN%20(Alzheimer’s).jpg)



The instructional philosophy of teaching PET to students is within the scope of the project *MMMM*. The teaching module of the PET activity will not stand as a single teaching module. Rather, different portions of the process will be presented throughout the year. For example, coincidence detection is introduced in kinematics chapter, detection of gamma rays in photoelectric effect and positron emission in radioactivity. At the end of the year, all pieces of activity are brought together and presented as a single module.

1.4 Design and Research Approach

The designed activities mostly used hands-on experiments. Interactive physical models were developed and students used those models to learn various physics ideas through hands-on learning experiences. A broad range of physics ideas including kinematics, light and modern physics were covered. These activities were designed to help students come up with correct target ideas, and develop their skills in applying physical processes. It also served to help to drive assessment to measure students' both factual knowledge and comprehension of various physics ideas.

Development and evaluation of such activities were based on the research on teaching and learning which builds on the existing research literature. Some of the traditional techniques of research such as clinical interview or student survey were used just to investigate what students know about a certain concept. To investigate what students know about PET itself and how they apply their prior learning to understand PET could not be achieved under clinical interview process. We could not expect that students who have not taken any physics course at college level know much about PET and modern physics concepts related to it.

Thus, the novel technique of teaching interview was adapted in the research. A teaching protocol was designed to help student learn several modern physics concepts related to PET and the technology itself. Although medicine, biology or chemistry were mentioned during the interview, the main emphasis in the protocol was on the physics parts within the technology. On the completion of the activities I did not expect that students could diagnose the disease by looking at the scan but rather focused on their explanation of the image formation method and physics ideas involved in the process. The learning goals of the activities were mostly qualitative problem solving because of the lack of sophistication in the devices used. Despite this students were encouraged to make quantitative calculations or approximations wherever and whenever possible.

1.5 General Research Questions

The purpose of the study was to examine students' knowledge, ideas and learning processes. The overarching research questions of the project are introduced in this section. In this particular research project, it was not considered to be sufficient to formulate precise research questions in advance for different stages of investigation. Instead, some preliminary results were expected to yield new research questions, so that the specific research questions could be designed for the subsequent stage of the research. Hence, the research questions presented in this section are the guiding questions that give an overall impression of the scope of the research presented in this dissertation. I will present the specific research questions in later chapters. The overall quest of the research project can be formulated by introducing the following questions.

1. How do the college students' learn the contemporary physics ideas related to PET?

Two important foci here are *contemporary physics* and *learning.* The research interest is to understand kinds of ideas student use in contemporary physics and classical physics. That means the inquiry is about the student learning process in two different physical worlds, macroscopic vs. microscopic. The study aims to explain if ideas used by student are scientifically accepted or not and if they are useful or not. The research also tries to find the factors influencing the learning processes.

2. What promotes transfer of physics knowledge while understanding medical imaging techniques?

For example, the study examines if students can use the learned concept successfully in a context where medical diagnosis process is involved. Another objective of the study is to reveal if and how the students use the strategies to make connection of physics with medical technology.

In order to decrease the range of the aspects of investigation of student ideas, student learning and learning transfer, different sets of specific and partial questions are formulated. These questions will be presented in the different chapters in the relevant places.

1.6 Overview of Research Strategy

The research questions posed above express a need for extremely deep understanding about the student learning process and their ideas. Hence, a qualitative research approach based on interviews and student documentation was implemented in order to meet the research objectives. However, a few alternative research approaches were used during the early stage of the research. Various theoretical and philosophical perspectives were selected consistent with the research approach. Using those perspectives the research was carried out as a three-phase effort.

A brief introduction of the research perspectives and phases of study are presented in this section.

The current research is guided by several theories of learning. Constructivism is one of the most prominent theories in guiding the research. Several inquiries about student ideas and their learning are made under this perspective. Along the lines of the theory, the research settings provide students an environment in which to engage them in learning and bring their current understandings to the forefront. Learning is viewed as a dynamic process under this paradigm where students construct new knowledge from previous knowledge through interactions with their learning activities. The research uses systematic scaffolding activities, including carefully sequenced hands-on and minds-on experiences in helping them construct their knowledge through such engagements. Several settings of the research encourage group interaction to enhance social interaction, where the interplay among participants helps individual students become explicit about their own understanding by comparing it to that of their peers.

Cognitive theory is used in the study in order to explain students' behavior in certain phenomena and make explicit their understanding. The theory has greatly influenced the research in exploring and analyzing nature of knowledge imbedded in students' responses. Based on this perspective, I tried to arrive at an understanding of students' thought process. Under the assumption of this paradigm, I have used complex problems with well-defined goals. Nevertheless, sequences of learning activities were arranged in order to enable the students to reach the goals. As demanded by the cognitive theory, the interview setting used several learning contexts that used the simulations reflecting real life situations.

This research used a phenomenological approach (Cohen & Manion, 1994; Holloway, 1997) where the structures of student experience, or consciousness is studied. Phenomenology, per se, is a branch of philosophy which aims to study how human phenomena are experienced in consciousness, in cognitive and perceptual acts. Phenomenology was used in this project as a research methodology with the aim of the exploration of the thought process of the students so that their perceptions could be identified and interpreted through series of interviews. My intent was to understand what students know or experience during learning processes and, therefore, I attempted to see their responses from their perspectives rather than a researcher's perspective. The effort allowed recognition of key themes of the student responses.

To identify and describe the qualitatively different ways in which students understand phenomena in the learning situation around them, the phenomenographic approach (Marton, 1986) was adopted. This was employed during the analysis phase of the research and the main intent was to explore the various ways students make sense out of the teaching activities. This research project, which involved three phases of the research effort, adopted the strategies mentioned above.

The first phase of the project involved the development of series of teaching activities. I interviewed pedagogical experts and conducted a thorough survey of literature to understand student difficulties in learning contemporary physics concepts related to PET. Based on results of the prior studies, the expert survey and student pilot teaching modules were designed. Pedagogical experts critiqued the developed material. The structure of instructional materials, which uses mostly hands-on and minds-on activities, tried to help students construct their knowledge. Student learning using the materials were investigated by having several groups of students using the instructional module in classroom and laboratory settings. The first phase of the effort resulted with the development of teaching activity for image construction process in PET. A teaching interview protocol was also created that would be used in the second phase of the study.

Individual teaching interviews were conducted in second phase of the research. The main purpose of this phase of the study was to investigate students' prior model of reasoning about physics concepts relevant to PET. Physical models were used to scaffold and challenge students' prior model of reasoning and their physics knowledge. The activities using physical models of PET provided a context for investigating the dynamics of students' learning and knowledge construction. Student transfer of learning with the facilitation of physical models was another interest of exploration in this phase. I tried to establish the variations in students' experiences and understanding in a particular phenomenon in the learning context through individual teaching interviews with students. Results of the study using phenomenographic (Marton, 1986) analysis provided the variations in the students' perception in the learning task and context.

A series of group teaching interviews were conducted in the third phase of the study. Students' prior models of reasoning and understanding explored through the second phase of the study provided the basis for the third phase of investigation. A set of learning experiences used in the second phase was introduced in worksheet format. Students worked in a group of 2-3 helped each other to learn physics ideas while interacting mainly with physical models with minimal guidance from the researcher. The phenomenographic approach was once again used to analyze the data. This phase of the study was carried out mainly to understand how the social interaction influenced students' model construction process.

Table 1.1: Study Timeline

Phases	Start data	End data
Development of teaching material and teaching interview protocol	Spring 2005	Spring 2006
Using the teaching activities and teaching interview protocol to investigate students model construction and learning transfer using physics model (conduct individual teaching interview)	Spring 2006	Fall 2006
Using the teaching activities, teaching interview protocol and feedback from individual interview to design group-teaching interview. Investigate group learning dynamics and social learning construction (conduct group teaching interview)	Fall 2006	Spring 2007

1.7 Overview of the Chapters

This dissertation consists of seven chapters. This chapter has presented the contexts and backgrounds that motivate the research. I have also tried to mention the bigger framework under which the study is conducted. The philosophical backgrounds of the material development and conduction of research are presented. This chapter also comprises the description of overall research plan and the project goals.

In Chapter Two I describe the positron emission tomography process. This allowed me to isolate various key physics concepts associated with this medical imaging technique. This chapter also outlines the prior research on student understanding on some of the physics ideas related to positron emission tomography. A short description of previous work on teaching physics in medical context is also presented. It also provides a comprehensive review of research related to physics education research and cognitive psychology. One of the major investigations in this research is student transfer of learning. A review of literature on transfer of learning is as well presented in this chapter.

Chapter Three describes the methodological perspectives adopted by the research. The presentation of several philosophical perspectives that underpin the study is followed by the discussion on the theoretical perspectives guiding the study. Also included in Chapter Three are methods used for the data collection and data analysis.

The development of instructional activities and research protocol are presented in Chapter Four. This includes pedagogical expert survey and interview as well as student tests. The learning cycle of Karplus (1977) was adopted as the teaching activity developmental strategy. A qualitative research method served to identify the expert's views on current pedagogical structure on teaching physics. The results of this phase of the study are a set of teaching activities for the phase two of the current research.

The main purpose of Chapter Five is to report the qualitative study on student learning processes. Students' learning and transfer of learning using physical model are identified. The results of the phenomenographic analysis are a set of identified themes.

The study on students' learning and learning transfer while interacting with their peers is reported on Chapter Six. Themes which emerged out of the analysis of student interview transcripts and worksheets during the investigation are discussed. Phenomenographic and thematic approach guides the analysis process.

Chapter Seven summarizes the key findings of the research. Results from phases two and three are discussed. Implications of the research findings to instruction are presented and recommendations for teachers and curriculum developers are summarized. Based on the results of the study the chapter proposes the directions for future research possibilities.

CHAPTER 2 - Background and Review of Literature

A section in this chapter provides an overview of positron emission tomography technology. Following this is a discussion on the isolation of different physics concepts associated with the technique. Another section in the chapter presents the overview of several efforts done in teaching medical aspects of physics at the undergraduate level. After this a section is devoted to discussions on the literature about student understanding of physics concepts such as photoelectric effect and radioactivity as some of the contemporary physics concepts involved in the PET process.

Constructivism being the guiding theoretical framework of this study an overview on constructivism and different types of constructivism will be presented. I also present a review of research literature on different types of student reasoning resources that are relevant to physics teaching and learning. In addition, reviews on literature in areas such as knowledge structure, modeling, and conceptual change are included in this chapter. Transfer of learning was one of the main parts of the investigation in the current research. The review of research in transfer of learning is discussed.

2.1 Physics of Positron Emission Tomography (PET)

2.1.1 Historical Background

Dirac solved the relativistic wave equation for matter on atomic scale and found the negative energy solution. He interpreted the negative solution of the equation as the indication of antiparticles (Dirac, 1928). This led him to propose the existence of a new particle, the *positron* as an equal mass, opposite charge pair to the electron even though it was not confirmed experimentally for next few years. Later, Anderson using a cloud chamber and a cosmic ray source was able to confirm the existence of *positrons* in 1933 (Anderson, 1933). Later Joliot & Curie (1934) were able to produce a positron-emitting isotope artificially. Using an alpha beam in an accelerator and aluminum as the target, they were able to produce P^{30}, a positron emitter with half-life of 2.5 minutes. Soon after its discovery *positron* played an integral role in the development of modern physics.

Positron emission has been used as a tool in various research areas. In their research work related to industrial application Maeda *et al.* (1996) have used the technique of positron emission to detect microstructural defects such as vacancies and dislocations in nuclear plant materials. Similarly, it has been used in basic physics research. For example Deng *et al.*(2002) used positron emission in finding out the cracks in semiconductor crystals. Recently, its application in polymer science has been reported (Satyanarayana *et al.*, 2006), where positron annihilation technique has been used as a tool for their study. They used the technique in separating liquid mixtures in polymers.

The application of positron emission in medical imaging and medical research began after the discovery of the positron and development of the cyclotron. Michael Ter-Pogossian is considered as the father of PET. His experiments beginning in the 1950s led to the development of PET as a practical diagnostic tool (Rich, 1997). The use of sodium iodide detectors to detect Cu^{64} in brain tumors dates back to 1951 (Wrenn *et al.*, 1951). The gamma camera was introduced in 1954 for the coincidence detection of positron emitting isotopes. After the introduction of the transaxial tomographic technique in early 1970s, the PET technology gained maturity as an imaging tool in nuclear medicine (Lundqvist *et al.*, 1998). During the last 20 years, great efforts have been made to improve the diagnostic accuracy of this imaging modality through the development of new data acquisition/processing systems and the introduction of new positron emitting radiopharmaceuticals (Tarantola *et al.*, 2003). Even though PET served as the medical imaging technique since the 1970's, its prominence in medical imaging field has occurred in the last several years.

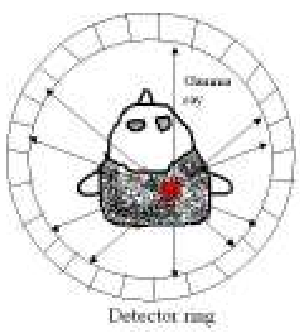
2.1.2 Process of PET

Physicists invented and started using the technology of Positron Emission Tomography. However, at present it is dominantly used in clinical medicine and biomedical research. In the nuclear medical field, it is regarded as a noninvasive imaging technique in creating images to show the physiological functions of certain tissues. A PET scan shows the abnormalities of metabolism caused by disease processes such as cancer, coronary heart disease and neurological conditions. Several steps involved in the image construction in PET are described below.

The first step involved is the production of a positron-emitting isotope such as C^{11}, N^{13}, O^{15}, and F^{18}. A cyclotron, which is a particle accelerator, is used for the production of the isotopes (Lundqvist et al., 1998). A stable chemical isotope is loaded into the target chamber of the cyclotron. After the proton beam bombards the stable target isotope, it changes into a radioactive isotope by means of a nuclear reaction. These radioisotopes are then transferred to a biosynthesizer unit in order to attach to biologically relevant molecules like simple sugar or glucose. This process is known as labeling.

The second step in the PET process involves the preparation of the patient. The radiotracer is introduced into the body of a patient few minutes before he or she is taken to the scanner because the half-life of the administered isotope is typically a few minutes. The type of the tracer used depends on the nature of the investigation. For example in carrying out most of the psychological studies the labeled isotope is oxygen (O^{15}), and it is injected into the body in the form of radioactive water (Goel *et al.*, 1997). The main reason for using the compound is that areas of the brain that are working relatively harder tend to get increased blood flow relative to areas that are not working as hard. As a result labeled oxygen concentrates in these areas which then have a higher oxygen concentration.

Figure 2.1: Image Construction in PET



Data acquisition with a PET machine is the final step in the process. PET detectors arranged in a ring collect the signals coming out from the patient body as shown in Figure 2.1. The processing of data extracts information related to the tracer's activity in the body. Finally interpretation of results is produced in the form of scan, which is analyzed to diagnose the illness or abnormality of a tissue.

2.1.3 Physics of PET Process

Even though the aim of the previous section was not a discussion of physics in detail, I managed to mention some of physics processes involved in PET. In reality, even more physics ideas underlie the process, and these physics ideas can be made explicit only if the explanation of

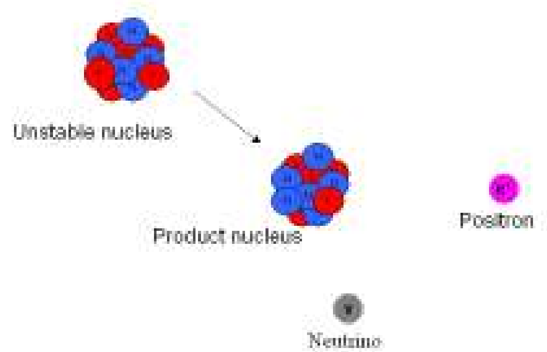
PET process is isolated into different steps. In this section I focus on the process as a physicist and discuss various physics ideas separately.

Positron Emission

The nuclei of the isotope, which is administered to the patient's body, emit positrons. The isotopes are unstable because they have large proton neutron ratios. A proton in such a nucleus decays to a neutron, a positron and a neutrino; as a result the product nucleus has an atomic number one less than the parent.

Figure 2.2:Positron Emission

(Adapted from University of Washington division of nuclear medicine PET teaching)



Positrons are singly positively charged electrons and typically have energy from a few keV to MeV (Raylman *et al.*, 1996). The rest mass of proton (and electron) is 9.1×10^{-31} kg which is equivalent to 511 keV as given by Einstein's mass energy relation, $E=mc^2$. The range of positrons in matter is in between that of alpha particle and gamma ray. A positron of energy of few MeV can be stopped by few millimeter of a tissue.

The isotopes to be useful in PET applications should meet some requirements. Obviously, they must emit positrons, and they also should have relatively short half-lives. If the half-life is very long, the injected sample of the isotope emits positron so slowly that PET "cameras" cannot gather useful information to construct image. On the other hand, the half-life should not be very small (less than a minute) either; otherwise all the signals are already missed before the imaging is done. Because of chemical considerations, isotopes of only those elements which can be used to label easily with molecules such as water, glucose and ammonia are used. (Murphy, 2004) Their natural occurrences in biological molecules, small atomic weights, and their ability to attach to biological interesting molecule with minimal or no impact in the behavior of the molecules in the human body are a few more considerations. Some of the most useful isotopes used in positron emission tomography are listed with their properties in Table 2.1. (Raylman et al., 1996; Siegel, 1999).

Table 2.1: PET Isotopes

Isotopes	Half-Life (min)	Maximum energy (MeV)	Maximum range (mm H_2O)
^{11}C	20.4	0.97	1.1
^{13}N	9.96	1.20	1.4
^{15}O	2.04	1.74	1.5
^{18}F	109.8	0.64	1.0

Electron-Positron Annihilation

A positron emitted from a decaying nucleus travels a short distance before colliding with an electron of a nearby atom. The positron being a charged particle gives up its kinetic energy mainly through coulomb interactions when traveling through human tissue. Because of the small mass, positron gets deviated significantly in each interaction. As a result, a positron follows a tortuous path while traveling in the tissue.

A positron, after losing most of its kinetic energy, eventually finds an electron in the tissue resulting in the process of annihilation. Electron-positron annihilation is the most important step that takes place in PET imaging process. In order to explain the annihilation process and its yield I want to put forward Dirac’s theory about antiparticles (Dirac, 1931). According to this theory, an antiparticle has negative additive quantum numbers that have the same magnitude as its particle counter part. The sign reversal applies only to properties or quantum numbers which are additive. For example, it doesn’t apply for mass but applies for charge. So, the positron, which is an antiparticle of electron, has a positive charge but the same mass as that of an electron. Dirac's theory has been experimentally verified (Anderson, 1933) and today a wide range of antiparticles has been detected.

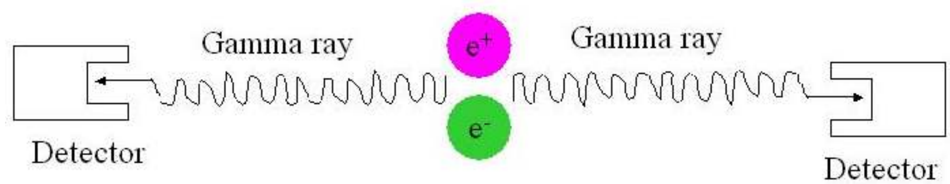
When a particle comes in contact with its antiparticle, the pair annihilate and the interaction produces a burst of energy. The energy goes either in the form of electromagnetic radiation or appears itself in the form of other particles and antiparticles. In this process, the rest mass of the particle-antiparticle pair may not retain in the same form rather mass is converted to energy. The mass-energy relation introduced by Einstein can be used to estimate the energy of the product. The electron-positron annihilation that takes place in PET produces electromagnetic radiation in the form of gamma rays. Using the rest mass of positron and electron, 9.1×10^{-31} kg, we arrive at the value of 2×511 keV of energy which is shared among the produced gamma ray photons.

The value of energy obtained after doing the mass consideration is true only if the electron and positron have no relative velocity. If the electron and positron are moving relative to each other, they have nonvanishing kinetic energy in their common center-of-mass reference frame. In such a situation, the energies of the particles that come out have to add up to be the same as the energies of the ones that went in. The result is that the energy of gamma ray photons adds up an energy greater than that obtained by doing only mass consideration. The possibility then is, of course, the gamma ray photons share equally the total energy coming out from the collision as well as rest masses.

Discussion about the number of gamma photon produced by an annihilation event is of prime importance in understanding the PET process. The positron and electron cannot annihilate to produce only one photon. That would violate conservation of momentum. The number of gamma photons produced depends not only on the momentum conservation but also on the angular momentum coupling of the electron and positron. An electron and positron at first create a positronium after the positron stops. Looking at this system in the center of mass, the net momentum is zero. To conserve the momentum of the system requires at least two photons. To know about the possibility of more than two photons, different states of positronium need to be discussed. (Ore & Powell, 1949) The coulomb interaction between electron and positron creates either an orthopositronium (o-Ps) or parapositronium (p-Ps). The former is a bound state of an electron and positron where the spins of the particles are parallel and the later is when the spins of the particles are antiparallel. For the orthopositronium case, which is also known as triplet state (S=1), at least 3 photons are required to conserve momentum and spin. More than 3 photons can be produced in this case, but the probability of getting more than 3 photons is a significantly low (Ore & Powell, 1949). On the other hand in parapositronium (p-Ps) case, also known as singlet state (S=0), 2 photons must be emitted. In all these cases, both momentum and spin conservation is satisfied.

The spin-averaged cross section of three-photon annihilation is two orders of magnitude smaller (Berestetskii *et al.*, 1982) than that of the two photon annihilation. The probability of production of 2 gamma rays is 373 times larger than the production of 3 gamma rays (Ore & Powell, 1949) if a free positron is involved in annihilation. The probability is even smaller to produce more than 3 gamma rays by an annihilation event. So, in most of the discussion in the PET process it is simply considered that two is not only the least number but also most probable number of gamma rays produced by an annihilation event. In this case, 2 gamma rays must move in opposite directions in order to conserve momentum.

Figure 2.3: Electron-positron Annihilation and Gamma rays Detection

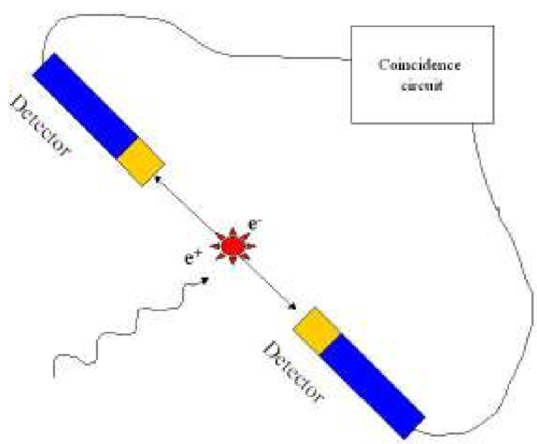


At present most of the PET scanners prefer the 2 gamma rays modality because of the higher possibility of two-gamma rays production by an event. As mentioned earlier 2 gamma decay of positron-electron annihilation is not the only possibility of an annihilation event. Multi photon decay is also probable however small it is. This fact has been considered recently (Karsperski *et al.*, 2004) to propose 3 gamma ray modality of PET. They argued that with the modality it is possible to provide valuable clinical information such as state of oxygenation of tumor. However, for the context of this dissertation, I do not go beyond the 2 gamma ray modality. Two gamma ray PET modality is preferred in the current study because this type of imaging is more common in practice and I also considered the instructional challenge.

Coincidence Detection of Gamma rays

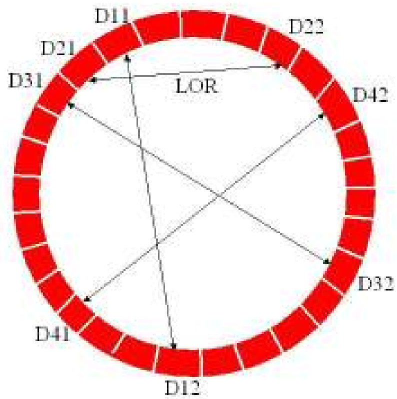
PET technique uses the idea of detection of pairs of gamma photons in coincidence. Detectors are arranged in a ring in PET scanner. A pair of almost collinear gamma rays each having approximately 511 keV of energy are received by two detectors. Each detector generates a timed pulse when it registers an incident photon. Two such pulses are recorded in coincidence electronics system only if they fall within a short time-window. For coincidence detection it is reasonable to think that the detector pair receive and gamma rays and produce pulse simultaneously. But in PET scanner time is required to process the information by using associated electronics. In general coincidence events are accepted if two events fall within a range of 4 to12 ns (Shukla & Kumar, 2006). The coincidence mechanism then indicates that pairs of gamma rays that produce the pulses within the coincidence time window are the result of a single event. The event is therefore stored and assumed to have happened on line joining the center of the detectors receiving the photons as shown in figure 2.4. The line is commonly known as line of response (LOR).

Figure 2.4: Coincidence Detection



One can infer that the annihilation event occurred somewhere along LOR. In this way, positional information is gained from the detected radiation. Every detected pair of coincidence events is stored as two-dimensional matrix called 'Sinogram' (Shukla & Kumar, 2006). This set of data in terms of a two-dimensional matrix provides a set of projection data for reconstruction of image. The information registered within the sinogram is decoded to reconstruct the image with the aid of image processing tools to produce a final image of the activity and thereby of the functionality. But the basic idea is that the region with the higher density of lines indicates the region with higher probability of having annihilation activity, which then eventually maps with the injected isotope activity.

Figure 2.5: Detector ring and LOR



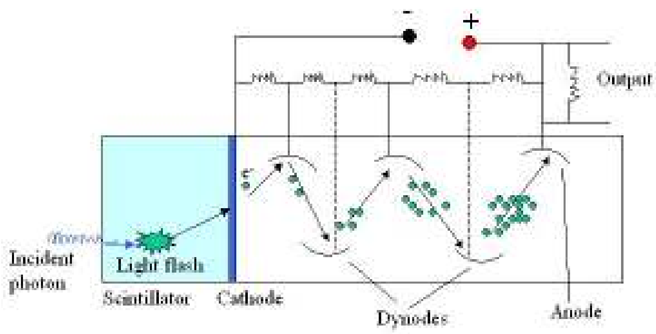
The simplest way to visualize the image construction process is to draw all possible LORs and look at the region where maximum numbers of lines intersect. This region has the number of maximum annihilations taking place and is the approximate region of interest. In some regions a high line density of lines occur but the events actually do not originate from there. This forms a kind of noise in the imaging process. But such regions of false activity generally have less intensity than the regions of actual activity. After the completion of the PET imaging reconstruction process a tomograph or a cross-sectional image of the human body is formed. This image is produced in the form of a picture, which is the one read by physicians to diagnose the diseases or by researcher to study human cognitive function.

PET Detectors

Detection systems are a key component of a PET scanner. The use of detectors in PET scanners have been mentioned earlier without mentioning their functional principles. In this section, detector systems are discussed with the emphasis on the involved physical processes. A detector in PET scanner uses mainly a scintillation detection system that couples with a photomultiplier tube (Ollinger & Fessler, 1997). The schematic of the PET detector is shown in Figure 2.6. The basic mechanism of the detector is the interaction of gamma ray photons with scintillation material to produce a flash of light which then generates an electrical signal in response to light incident upon its face.

The conversion of gamma photons into visible light in scintillation material takes place either by photoelectric absorption or by Compton scattering. During the photoelectric effect, an incident gamma photon creates an energetic electron by interaction with the material. The electron then passes through the scintillator, loses its energy and excites other electrons. Finally these excited electrons decay back to their ground state, giving off light.

Figure 2.6: Photomultiplier tube



The scintillation materials in the PET detectors are chosen such that the material has practical importance when receiving the gamma ray photons of energy 511 keV. More specifically stopping power, amount of light produced against each absorbed photon and time taken for the decay of light are the important material characteristics which are considered.

Materials having higher stopping power are used in order to increase the efficiency of the absorption of the energy of photon. A scintillator with a high effective atomic number and linear attenuation coefficient are suitable for this purpose. A gamma ray interacts with matter by the mechanisms of photoelectric effect, Compton scattering and pair production (Kaplan, 1962). Pair production, which occurs only for high energy photon, is not possible for annihilation photon with an energy of 511 keV. Photoelectric interactions are dominant if the material of high atomic number and the photon of low energy. In order to have high energy resolution of the detected photon, the detector should have a capability of producing high light output. The accuracy in the coincidence detection is highly influenced by the decay time of the light. The scintillation material with shorter time constant enables faster production of the signal after light absorption. This consideration is very useful in PET because it helps to narrow down coincidence time window.

Sodium iodide (NaI) has been used as the scintillation material since 1950's. The NaI crystal of length 4 cm and area of cross section $2cm^2$ gives the detector sensitivity of 70% (Lundqvist et al., 1998). Because of the higher area of the crystal the spatial resolution is lost. When the area is decreased, Compton/photoelectric ratio goes high and sensitivity decreases due to loss of Compton photons. Bismuth germanate (BGO) was introduced to overcome the problem where detector sensitivity of 70% was reached with a crystal of length 1.5cm. In this case the Compton/photoelectric ratio is also low but BGO has the drawback that it is very slow crystal. It is not very useful when one wants to design PET with the coincidence time window small. In order to have extremely small time window CsF crystal is used as scintillator because the exited electrons decay extremely fast in this crystal.

The photomultiplier tube in the detector consists of a photocathode, an array of dynodes and an anode in an evacuated glass tube. The function of the photocathode is to convert the light flashes produced by the scintillation crystal into electrons. The number of electron is multiplied by the dynode array is used for electron multiplication in order to produce significant size of electric pulse to be registered.

Time of flight PET

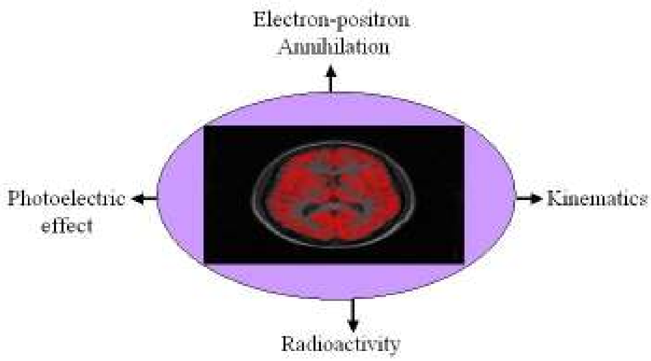
The conventional PET systems form LOR in order to locate the annihilation events. However, using an LOR it is not possible to determine the exact location of each annihilation spot individually. Thus, these scanners use statistical methods and form sinograms. The exact determination of each annihilation location is preferred in recent years.

Exact location of each annihilation events provides more accurate information about tissue because there is low level of noise signal (Moses & Derenzo, 1999). The annihilated photons may reach the detectors at different times unless the annihilation events occur at a position that is exactly located in the middle of two coincident detectors. The difference in arrival time of the two gamma rays is extremely small because the photons travel with speed of light. In a typical PET scanner detector the time difference is in an order of 1 nanosecond. This fact is exploited to develop a more sophisticated PET, which is known as time of flight PET or TOFPET. This technique allows helping reduce noise in imaging significantly. The key physics idea involved in TOFPET is the time of flight measurement and distance calculation. So, a simple kinematics equation involving speed, distance and time is enough to describe the process.

2.1.4 Summarizing the Physics Involved in PET

The discussion above about the PET process gives the idea that the process involves large number of physics concepts. A few examples of the physics concepts involved in the process are summarized in Figure 2.7. Radioactivity is involved during the emission of positron by unstable isotope. The process of electron and positron annihilation to give rise two gamma rays is explained by Einstein's mass energy equivalence relation. Principles of conservation of momentum, energy and charge are also involved in electron-positron annihilation. The distance, time relationship is useful in locating the annihilation place. The detection of the gamma ray photons is understood by the understanding of photoelectric effect.

Figure 2.7: Physics Concepts in PET



Out of several ideas discussed above, some physics ideas are very simple and students of even the conceptual level can make sense easily. Obviously, the distance-time relation and momentum conservation are some of the key ideas of the PET process that students do not find new. On the other hand, there are few ideas such as projection of different LOR, formation of sinograms and reconstruction of image that can challenge even graduate level physics students. However, most of the physics ideas involved in PET are about the level suitable for introductory level algebra-based physics. The list of the examples of such concepts contains modern physics concepts such as radioactivity and photoelectric effect. Students are not comfortable with some of the modern physics concepts such as annihilation and mass energy relation at this level. However, they can be helped in that area by providing situations such that they can make connections with other physics ideas they already know from prior classes or experiences.

Positron emission tomography is introduced in some of the introductory physics textbooks. But the presented material is very brief and is focused on only one or two physics ideas. The current pedagogical structure doesn't allow using PET as a context where students can apply their physics learning. I am not emphasizing that PET or other medical techniques should be taught in physics class in detail, nor do I insist that students in introductory level or pre- med course should be able to understand PET as radiologists or PET experts. The only thing I want to mention is one can use the strategy to build a foundation in the related concepts so that students can use them to understand the underlying physics ideas.

2.2 Teaching Medical Physics Course

It has been noticed for several years that advancement in physics and medicine go hand in hand. Several physics discoveries have been exploited by medical applications. Due to this fact, physicists are increasingly listening to the demands of the medical profession not only in defining the direction of new research but also in designing courses in physics. Along this line, graduate level medical physics courses have been designed and taught to students in different parts of the world for last few decades. The purpose of such courses is to train students to make them medical technicians.

In order to fill the gap between introductory physics and its application to the life and biomedical sciences, few courses have been introduced in physics departments (Poepping, 2006; Wilson, 2003). However, the intended audiences for such courses are advanced undergraduate and beginning graduate students in biophysics, physiology, medical physics, cell biology, and biomedical engineering. In such courses, students are expected to be able to explain the physical principles underlying the different areas of the application of physics to medicine. The expectations of such courses are also to make students able to explain the advantages and drawbacks of different methods of treatment or investigative techniques and make them aware relevant research in medical technology and its improvements.

Teaching physics courses with medical contexts to undergraduate level students is not common. However, some efforts in this area have been reported (Amador, 1994). One of the goals of such courses is to motivate students in physics learning by making them aware of application of physics in medical context. Another goal is to help them learn some medical aspects of physics so that they can apply such ideas in their future learning and eventually in their future career. Some introductory level physics courses are designed such that they show how some of the physics learnt in a number of core modules may be applied in an important area outside of physics.

It is considered challenging to teach medical aspects of physics to students who never took college physics before. The main reason could be the various modern physics concepts involved in medical technologies. Not much work has been reported in the area of teaching and curriculum development of physics course for such audience. However, few years ago Zollman (2002) undertook development and teaching of a physics course for pre-medical students. In this course he focused on the application of physics in medical diagnosis techniques. The course focused on the various topics such as X-ray, computed tomography (CT), positron emission tomography (PET) and magnetic resonance imaging (MRI). The medical contexts were introduced in various physics topics by using hands-on activities and visualizations. The effort not only helped students learn the relevant physics content but they were also pleased with the type of material used (Zollman, 2002).

In order to emphasize the awareness of physics relevance in everyday life, some high school physics courses included the medical contexts several years ago (Ronen & Ganiel, 1984). The continuity of such efforts is reported recently (Gibson *et al.*, 2006). The use of the field trip to hospitals (Ronen & Ganiel, 1984), visualizations and use of research resources (Gibson et al., 2006) are the features of such courses. The overall aim of such efforts is to highlight some of the areas of medical physics that are relevant to teach in a secondary level physics course. The teaching resources for the teachers included the PowerPoint teaching material, posters, textbook and images from other sources. Various web links were also available for teachers and students. Electromagnetic spectrum, radioactivity and ultrasound were the areas of physics contents included in the course. The course emphasized the medical aspects such as thermography, ultrasound, x-ray, endoscopy and PET. The authors have raised very interesting issues such as use of students' prior medical experiences in class, and application of their knowledge gained through news media. Usually, there is low participation of female students in physical science classes, but the authors report that the male and female enrollment in that class was even.

2.3 Previous Studies on Student Understanding of Physics Related to PET

Not much education research has been devoted to the student understanding of modern physics ideas relevant to PET. Most often the subject of PET is considered a medical topic rather than physics topic. However, as an invention of physics it has had some presence in physics literature but the subject is far too specialized for presence in mainstream, physics education literature. Some of the work that has been done is reported mainly in medical and physics journals but not that related in physics teaching. Even though serious research on students learning of PET has not been reported, some work has been reported in the area of development of teaching activities of PET (Johansson *et al.*, 2006; Sonnabend *et al.*, 2002). In both examples the activities are aimed at physics major students. The models are designed to demonstrate to the students how PET works.

To date, a few studies have been reported in the area of student learning of some of the physics ideas related to PET. Those works do not focus, however, on student understanding of the respective concepts in the context of PET learning. The development of teaching activities related to physics of PET can be guided by the research findings. So, a review of some of the prior works done in the two of the modern physics concepts involved in PET is presented below.

2.3.1 Previous Research on Student Understanding of Radioactivity

Mainly middle school, high school and college level students' ideas about radiation and radioactivity have been studied. In Europe some of the research studies showed that middle and high school students have weak understanding in absorption properties of radioactivity and radiation. After conducting interviews and diagnostic tests with high school students (Eijkelhof & Miller, 1988) found that a large number of secondary level students have problems in differentiating radiation and radioactivity. The research indicated that the students consider that radiation coming out from an object affect the other objects in their vicinity and make them radioactive. In his work, Miller (1994) has shown through diagnostic tests that the high school students have difficulties in differentiating irradiation and contamination.

Similar types of research have been done in the US. However, these studies are focused on college students rather than the high school students. While investigating introductory level physics students ideas about radioactivity and radiation, Prather and Harrington found a result similar to the European one (Prather & Harrington, 2002). They used the diagnostic tests and the questions using various situations involving contexts where objects were exposed to radiation. Most of the participant students stated that objects exposed to radiation would either become sources of radiation or have radioactive properties. Some of these students described that the ionizing radiations have the same properties as radioactive materials. It is very interesting to note that the college students apparently did not change their ideas significantly in spite of having taken the additional classes in radioactivity and physics in general.

In their work Aubrecht & Torick (2000) have indicated similar type of results that other studies did. They used open-ended questions and ranking tasks in conducting student interviews. Through this study, they have shown that students believe that nothing is radioactive unless it is exposed to radioactivity. The study also reported the students' idea that machines make radioactivity and there was nothing radioactive before such machines existed. Those students considered microwaves as one of the sources of radioactivity.

Prather (2005) also conducted research using a series of interviews with the introductory level physics students. The goal of his study was to understand the students' ideas about the role of atoms in connection with radioactivity. In this study, he found the students' belief that the radioactive atom disappears when it decays. By looking at the students' drawings he confirmed that 59% of these students believed that the mass and/or volume of a radioactive object would decrease by half in the period of a half-life. It was also confirmed that the majority of the students (53%) held the valence electron model of radioactivity where students think that radioactivity is the result of valence electrons.

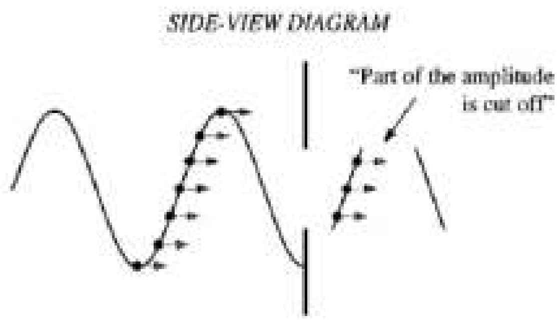
2.3.2 Previous Research on Student Understanding of Photoelectric Effect

The photoelectric effect is important for historical reasons and shows its presence to a large extent in basic physics literature. Only a limited number of studies has been done on teaching and learning related to it. Some of the studies have reported student understanding of ideas such as photon model of light (DeLeone, 2004). A brief overview of some of the works related to the photoelectric effect is described below.

The physics education research group at the University of Washington undertook research on student understanding of the photoelectric effect within a framework of investigation of student understanding of physical optics (Ambrose *et al.*, 1999). The researchers reported that many introductory and advanced students who have studied physical optics do not have a functional understanding of wave model for light, and they have difficulties identifying the conditions under which situations the wave model should be applied. Along this line, they have also conducted research on student understanding of photon model of light that led to the development of a computer-based tutorial to help students apply a photon model to the photoelectric effect (Steinberg *et al.*, 1996).

The main goal of the research on student understanding of single and double slit experiment (Ambrose et al., 1999) was to investigate students' difficulties in understanding wave and particle nature of light. The participants of the study were introductory algebra-based physics and modern physics students. The students of the introductory level physics had already covered geometrical optics whereas modern physics students had covered wave nature of light. The research tool of the study was individual demonstration interview that involves student interview using a demonstration. The results of the individual demonstration interview were then used to create several interview questions and that were used in the large student population.

Figure 2.8: Student Photon Model of Light Accounted for Single slit Experiment



The results of the study showed that while using the photon model of light students expressed the idea that each point on the wave is a particle. When the wave passes through the slit, some portion of light is cut and only the particles within the unobstructed portion can pass through the slit. Students also consider that the path of the particle or photon is sinusoidal.

The researchers considered that understanding of the photoelectric experiment is very crucial in order to develop photon model of light that led them to investigate student understanding of photon concepts in the context of photoelectric experiment (Steinberg et al., 1996). The student concepts of photon as investigated by the other study were used to design the interview questions. These interviews were conducted with six students from the modern physics class at the University of Washington. All participant students had completed the photoelectric effect topic in the class already and their class performance was also good. In the interview the students were asked to draw and interpret a graph of current versus voltage for a photoelectric experiment. Whenever some students were not able to draw the graph, they were shown the graph from their textbook and then asked to explain the features of curve. To further probe the students' understanding, they were asked about the effect on the graph of a change in intensity or frequency of the incident light.

The study indicated that the students who attended the lectures in the photoelectric effect topic without laboratory and discussion sessions were not able to grasp the photon model of light and also could not interpret the experiment of photoelectric effect. In yet another finding they report that students had problem in drawing I-V graph in photoelectric effect experiment (Steinberg et al., 1996) The major problem in student drawing was that they were not using the photon model of light. Students had strong belief that Ohm's law of voltage and current applies to the photoelectric experiment. There were some other interesting results such as students' inability to differentiate between *intensity of light* and *frequency of light*, and inability to give an explanation relating to photon in photoelectric effect. They also reported a very surprising result that students believed that photon is a charged particle.

Drawing on the results from the study the researchers developed a computer tutorial, which not only served as instructional tool but also as a research tool. The tutorial's main emphasis was to help students plot and interpret I-V graphs in the photoelectric effect accurately. As a research tool it was found helpful in investigating student reasoning, and student difficulties. Researchers (Steinberg et al., 1996) claim that students performed significantly better in I-V plot exercise and could interpret it more clearly than before. They argue that the students' better performance could be because of the students' intellectual engagement using the tutorial.

Studies of pre-university students' difficulties in understanding quantum phenomena including photoelectric effect have also been carried out in Europe (Fischler & Lichtfeld, 1992; Ireson, 2000; Jones, 1991; Petri & Nieddrer, 1998). The studies reported students' difficulties in understanding photoelectric effect. The studies identified that the root cause of the difficulties in understanding photoelectric effect is the student held inaccurate photon model of light. Jones (1991) found the student difficulties in introducing the term photon early on in introductory level physics course. One of the studies shows that students think that the photon is a small spherical entity (Ireson, 2000). Students therefore always try to relate photon with classical objects. The researchers recommend using the term quantum of light rather than photon in context of teaching photoelectric effect. This might minimize the students making connection of photon with classical object.

2.4 Constructivism

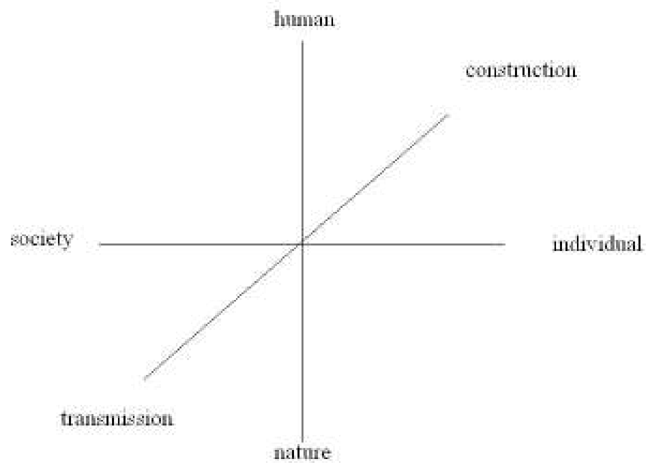
The idea of constructivism is accepted both as a theory of learning and theory of knowledge. As a learning theory, it is based on the assumption that a learner constructs learning by reflecting on own experiences and make sense of the world through that construction. So, learning is the integration of new knowledge gained with anchoring pre-existing intellectual constructs. Learning as viewed by constructivist perspective is simply the process of adjusting one's own models of ideas to accommodate new experiences. It views that knowledge is actively constructed by the learner and not passively transmitted by the educator. The creation of new knowledge takes place by testing ideas and prior experiences while applying to new situations. The key mechanism of the process is that knowledge is broken down into information and then constructed.

Constructivism serves as a theoretical framework for both the research and instructional material development presented in this dissertation. This research emphasizes students learning in terms of the process and not the product. How students arrive at a particular reasoning or answer is more important than their retrieval of a true solution. How students construct meaningful representations and make sense of their experiential world is another focus of the study. While investigating students' answers or responses student made errors are seen in a positive light and as a means of gaining insight into how they are organizing their experiential world. This framework of the research is consistent with the constructivist tendency in the sense that it acknowledges multiple truths, representations, perspectives and realities.

In the following discussion, I present a brief review of the various streams of constructivism in studies of education research and mention where this research fits. Phillips (1995) has described three varieties of constructivism placing them in three dimensions as shown in Figure 2.9. The first axis or dimension is labeled as "*individual psychology versus public discipline*". The views on the constructivism that focus on how individuals construct knowledge through their own cognition are placed on one end of this axis. So, the constructivists such as Piaget (1964) and Vygotsky (1978) are the prominent examples of that end. However, Piaget stressed the biological and psychological mechanisms to be found in the individual learner while

Vygotsky focused on the role of social interaction in an individual constructing knowledge. Constructivists who place little importance on individual learner and focus on construction of human knowledge in general fall at the other extreme of this axis. This group of constructivists concerns itself with the public bodies of knowledge and explaining how they are socially constructed and interpreted in terms of changing social conditions and interests.

Figure 2.9: Three Axes Representing Forms of Constructivism



Philips labeled the second axis as the *human the creator versus nature the instructor.* The constructivists who believe that knowledge is constructed within learners' minds by some cognitive process fall at one end of the axis. Theorists at the other extreme of the axis assume that knowledge is outside the learners' mind and it is imposed to them passively.

The third dimension is concerned with how the learning takes place. Philip has not used any label for this axis but he places the different theorists at different places along this axis based on whether they believe *knower is actor* or they use *spectator theory of learning*. This is the axis labeled as *construction* versus *transmission,* then *knower is actor* view is obviously close to construction of knowledge end whereas the *spectator theory of learning* falls to the other end.

The study presented in this dissertation uses the perspective that students create knowledge individually. The construction can be either with the help of other people or by the learners themselves. So this research fits near the *individual* end of the first axis. I believe that natural world has to do with the organization of the knowledge but learners are responsible for creating knowledge. Therefore, regarding the second axis, this study is more situated towards the *human* end. This research adopts the perspective that students learn by active engagement, so I incline towards knower the actor rather than knower the spectator. So, this study chooses to be at the construction end of the third axis.

Even though I pinpointed the coordinates of the perspectives used by this research in the three dimensional space of constructivism I mainly focus on one dimension. As mentioned earlier within the *individual* end of the first axis two different theoretical views of constructivism exist. The first one is Piagetian individual constructivism (Piaget, 1964) and second is Vygotskian social constructivism (Vygotsky, 1978). These are most commonly used constructivist theories in the contemporary teaching learning contexts, which emphasize active learning to help students learn by themselves or with social interaction. Most of the discussion of this research are under the framework of these two views of constructivism therefore it is reasonable to describe those perspectives in more detail.

2.4.1 Piaget's Theory

Piaget considered two major factors *adaptation* and *organization* to explain the development of human intellect. He viewed *assimilation* and *accommodation* as two *important* processes involved in adaptation. In addition he also added *equilibration* to describe all possible processes that takes place in mind. The discussion of Piaget theory and its implication in instruction and education can however be possible with the introduction of *schema*.

According to Piaget a schema is an individual's mental representation of perceptions, ideas, and actions. These schemata are basic building blocks of actions or thoughts that help to create a mental representation of the object and events of the world (Woolfolk, 2001). With intellectual development new schemata are developed and existing schemata are more efficiently organized.

The process of assimilation takes place when we attempt to use our existing schema to make sense of a new event. This process involves trying to understand something new by fitting it into what we already know. Accommodation takes place when we respond to a new and unusual situation that does not fit with the pre-existing schemata. If new information cannot be made to fit into existing schemes, a new, more appropriate structure must be developed so as to adapt to a new situation.

The third type of adaptive process known as *equilibration* takes place when we encounter new information that is too unfamiliar and none of *assimilation* or *accommodation* can take place. When this occurs, we do the complex act of searching for the balance in organizing, assimilating, and accommodating. It is the state of disequilibrium that motivates us to search for a solution through assimilation or accommodation.

The process of *organization* refers to the structuring of the adapted mental material. Piaget proposed an idea that the organization of the mind is achieved through a series of complex and integrated processes. The simplest organization of knowledge is referred to as the schema. We always try to find a way to fit the external reality with our own internal cognitive structures, or schemas. Assimilation occurs when we try to map new objects or events in terms of existing schemas or operations. On the other hand, we may face some reality and cannot fit into the existing schema. In such cases, we have to alter our internal mental structures to adjust to the newly exposed external reality. Therefore, we can accommodate our internal mental structures to the external reality. So, the main idea is that number of assimilation and accommodation lead to the mental development that makes schema more complex and integrated. So, an intellectual development can be referred as increment in the complexity of schema.

Piaget has claimed that there are four stages of intellectual development. The first one which he called as the *sensorimotor stage is* demonstrated by children of 0-2 years of age. In this period intelligence is demonstrated through motor activity without the use of symbols. It involves seeing, hearing, moving, touching, and tasting. Knowledge of the world is limited because it is based on physical interactions/experiences. The second stage is known as *the preoperational stage, which* takes place in the children of age2-7 years of age. In this stage intelligence is demonstrated through the use of symbols. Memory and imagination are developed but thinking is done in a non-logical and non-reversible manner. Piaget named the third stage as the *concrete operational stage* and it is demonstrated by children of 7-11 years age. Any one demonstrating this intelligence undergoes logical and systematic manipulation of symbols related to concrete objects. With the operational thinking development, an individual has understanding of reversibility and mastery of two-way thinking. The last and fourth state is called *formal operational stage.* This stage takes place in a person of 11 years or older. A person at this stage demonstrates intelligence through the logical use of symbols related to abstract concepts. Concrete symbol or objects can be used to draw abstract reasoning. The individual doing *formal operation* has the ability to think logically about intangible concepts, about possibilities, about hypotheses.

Some of the studies have been reported to extend Piaget's developmental theory. In a study with US freshman college students, Mc Kinnon and Renner (1971) showed that the students were mainly in concrete operational level. They, however, claimed that students formal operation was facilitated when inquiry-oriented course was used to the students. This study suggests that we cannot guarantee that students' development is totally dependent on their ages. The relevance of Piaget's intellectual developmental theory in physics teaching has been put forwarded through an AAPT workshop (Karplus et al., 1975). The workshop used the idea that college students' reasoning about physics problems is context dependent. A student using a formal operational reasoning in a problem could use concrete operational reasoning in another problem. Research by Das Gupta and Bryant (1989) showed that children at an age as early as 4 years can exhibit the reversibility. They conducted an experiment with children of ages 3 years and 4 years. The experiment showed that children of 4 year olds could understand a simple, familiar transformation and follow it mentally in both directions exhibiting reversibility, which according to Piaget's original work could be possible only at ages of 7 years or more.

Case (1985, 1992) put forward a theory that contains some aspects of Piaget's four stages but he further segmented each of the stages into sub stages. The four stages are named as sensory motor stage (from age 0- 18 months), interrelational stage (18months- 5 years), dimensional stage (5 years-11 years), and abstract dimensional stage (11 years-19 years). The first stage is divided into four sub stages and the rest of the stages into three sub stages each. This theory, which uses the information processing approach, claims the increase in working memory capacity in each of the stages as a result of maturation and practice. The Case's developmental theory has been applied to describe the children's concepts of energy (Liu & McKeough, 2005). The dimensional stage that spans from the age of 5-11 is discussed in that context. They claim that children at the first sub stage of this stage bring the idea of food driven human movement and fuel driven nonhuman movement together to build an energy concept-energy as activity. At the next sub stage (age 7-9 years) children start to think that energy is capacity of doing work. During sub stage 3 (age 9-11 years) children elaborate the previous structure to integrate into higher-level structure and consider that energy has various sources.

The main idea presented in the above discussion has two aspects. The first aspect is about the process of learning, which is described as change in schema. The second one is about the categories of thinking, which is presented under the framework of different operation stages.

This research incorporates both the aspects of this model of learning. I try to investigate what schema a student could have and what process might have taken place for the change. In physics learning contexts, students can go under any form of *adaptation* depending upon what they already know. On the other hand, in terms of Piagetian categories of thinking, I do not make any assumption that students function in one mode or the other. Rather through the process of teaching interviews, we investigate students' thinking without placing them in any of the operational stages. The activities used during the teaching interview provide students experiences to help them develop from concrete thinkers to more formal thinkers.

Piaget's idea has been applied in physics teaching for last few decades (Fuller, 1980; Karplus, 1977; Renner, 1982). Karplus (1977) has been influenced by the Piagetian theories of development. Karplus argues that science learning should be a process of assimilation and accommodation in which the students form new reasoning patterns. He proposes a three–phase learning cycle to help students learn through self-regulation. The phases are known as exploration, concept introduction and concept application. Students learn through their own actions and reactions with minimal guidance in the exploration phase. The second phase in the learning cycle is analogous to assimilation or accommodation when new structures are built to integrate new information. The third phase is designed to provide the students with active learning situations where they can apply, test and extend the new ideas and concepts. This phase is analogous to equilibration.

Renner's approach of teaching science is also influenced by Piaget's theory and it also uses three stages (Renner, 1982). At first, the material to be taught can be given to the students as information; second, it is then verified by the students through observation; and finally, the information is applied to settle the newly constructed knowledge. Few more pedagogical frameworks have been devised in science education that center on Piaget's theory (Barnes, 1976; Driver & Bell, 1986). These frameworks use a teaching-learning strategy that involves *experience, interpretation, and elaboration;* thus they all fit under the general name of the learning cycle. In the 1980s the Learning Cycle was adapted to many university situations including a curriculum for freshman college students (Fuller, 1980) and in larger enrollment classes (Zollman, 1990).

2.4.2 Vygotsky Theory

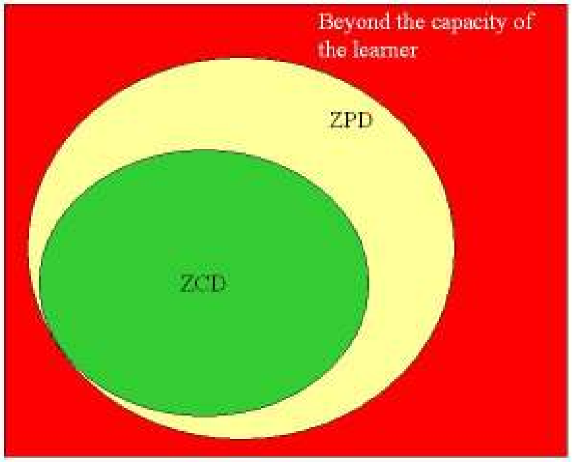
Vygotsky stated that social interaction profoundly influences learning and cognitive development (Vygotsky, 1978). He further emphasized the role of culture and importance of language. In contrast to the work of Piaget he assumed that biological and cultural developments do not occur in isolation (Driscoll, 2000). His learning theory is relevant in contemporary instructional designs, which are rich in peer interactions and teacher–student interaction. Such environments provide ample opportunity of knowledge construction during social interactions where a teacher should collaborate with his/her students in order to create meaning in ways that students can make their own (Hausfather, 1996). Learners form and test their constructs in a dialogue with other individuals or society. In this situation, collaboration is the activity useful for negotiation and testing of knowledge. Therefore, in such learning contexts, mostly open-ended evaluations are performed for the learning outcomes assessments.

In order to explain the learning in social contexts Vygotsky proposed a model called *Zone of Proximal Development (ZPD).* Learning occurs in the *zone of proximal development* when learners are supported via social interaction to go beyond what they already know and can do. He defined ZPD as (Vygotsky, 1978):

> "Zone of Proximal Development is the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers."

In simpler words, ZPD is the gap between what a learner can accomplish independently and what a learner can do with assistance of others. The understanding of ZPD can be simpler if two other terms are introduced. The first of them is *Zone of Current Development* or ZCD. A learner is said to contain within one's ZCD what he/she can do it independently. The second term is *More Knowledgeable Other* or MKO. MKO is a more capable peer or teacher who helps a learner accomplish tasks that may be in the learner's ZPD. Different zones of development can be visualized with the help of Figure 2.10.

Figure 2.10: Locating Learners Zones of Development



Scaffolding is one of the strategies to access the zone of proximal development (Bruner, 1966). Scaffolding requires the teacher to provide students the opportunity to extend their current skills and knowledge. A learner's ZPD can be extended with scaffolding from instructors, peers and learning materials ((Bonk & Cunningham, 1998); (Gredler, 1997) and (Bruner, 1984)). The teacher must engage students' interest, simplify tasks and motivate students to pursue the instructional goal. In addition, the teacher must look for discrepancies between students' efforts and the solution, control for frustration and risk, and model an idealized version of the act (Hausfather, 1996).

Figure 2.11: Four Stages of ZPD

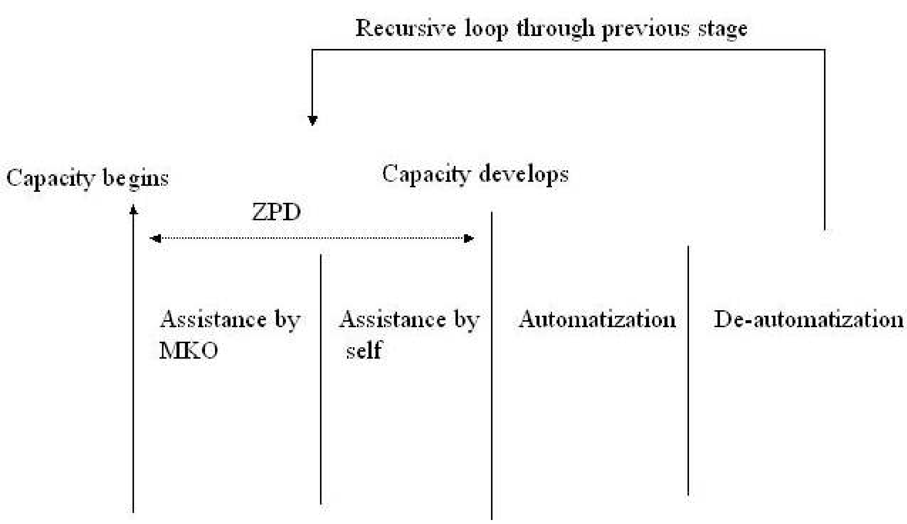


Figure 2.11 which was proposed by Tharp & Gallimore (McInerney & McInerney, 2002) describes the ZPD as a four-stage process. In the first stage assistance is provided to the learner by MKO's such as parents, teachers, experts and peers. Assistance is provided by self in the second stage in order to increase the proportion of his/her responsibility for participation in the task. In third stage the learners tries to get automatization through practice. The main process in this stage is the internalization of the new learning through practices. The fourth stage involves the de-automation of performance which leads to recursion back through the zone of proximal development. The recursion usually takes place when the learner faces a new context and cannot perform the task leading to recursion to the first stage.

Vygotsky's theory has been used in physics teaching and learning for few decades. In Socratic dialog instruction format (Hake, 1992), students construct their knowledge through teachers' guidance. Peer instruction (Mazur, 1997) uses the idea that students help each other in challenging each other's idea through discussions. Cooperative group problem solving (Heller *et al.*, 1992) uses the strategies of group learning. Teachers serve as MKO in the Socratic dialog strategy whereas more capable peers are MKO in the rest two approaches. In all those instructional formats the researchers reported that students' learning accomplishment in a group is beyond what they could do individually.

This research is framed under the various aspects of Vygotsky's constructivism. During the student teaching interview, I provided several scaffolding activities and hints using hands-on activities about various physics concepts involved in PET to help students build scientifically accepted ideas and reasoning. The group teaching interviews used in the later stage of this research are based on Vygotsky's idea of learning within the zone of proximal development via group interaction.

2.5 Student Reasoning Models

Physics education researchers have long recognized the importance of identifying students' physics reasoning elements in different physics contexts. The study on coordination and organization of those small elements in the memory is an area of research in physics education as well as cognitive psychology. The investigations of knowledge structures of students in context of various physics concepts provide ample opportunities to researchers for finding out the general processes of how students understand, reason and use the concepts. The outcome of such effort leads teachers, and instructional designers in facilitating student learning via appropriate selection of knowledge and instructional strategy.

A large body of literature covers the student difficulties and misconceptions about various physics ideas (McDermott, 1984; McDermott & Redish, 1999; McDermott *et al.*, 1994). But in last several years physics education researchers have focused on the students' resources as valuable input in teaching and learning physics (Hammer, 2000). The researchers consider that the student resources should provide theoretical underpinnings to understanding students' misconceptions and difficulties as well. They have also advocated that such cognitive structures are more general than student *misconceptions* and *difficulties* and are productive in designing classroom instruction.

Various researchers have described different conceptual constructs that students bring into physics classrooms. Hammer (2000) used the general term *resources* to refer those conceptual constructs. One such resource was described by Clement *et al* (1989). They regarded that student's prior ideas can be productive in learning new material therefore not all preconceptions are misconceptions. They put forward the idea of *anchoring conception* and *bridging analogy* as productive resources in students' understanding. Another conceptual resource has been introduced called *raw intuition* and it is described that *raw intuition* can be refined and can serve as useful learning resource (Hammer & Elby, 2002). diSessa's phenomenological primitives or "p-prims," has been considered as a precise model of cognitive structure. (diSessa, 1993) According to this notion p-prims are considered as one form of primitive cognitive structure. Few more models of conceptual resources such as facets (Minstrell, 1992), and coordination class (diSessa & Sherin, 1998) have been proposed. In the following subsection I present some of the small scale model of reasoning put forward by physics education researcher in the last few years.

2.5.1 Phenomenological Primitives

In providing the framework for describing and correlating characteristics of a weakly organized knowledge system (diSessa, 1993) has proposed the concept of students' intuitive knowledge in physics. diSessa's theory is the based on the interviews of 20 introductory level physics students. The students were interviewed at different times during three years to investigate student understanding in physics. Through this study he was interested to see the element of knowledge system and student use of those elements to explain the physics concepts.

The study of diSessa provides hypothetical knowledge structures called phenomenological primitives or p-prims. The term phenomenological in p-prim implies that p-prim is the interpretation of reality based on observed phenomena. diSessa claims that p-prims are primitive knowledge structure because they are simple, and unproblematic with minimal abstraction.

He has described some properties of p-prims. The first property is that it is a small knowledge structure that is self-explanatory. So p-prims act as the intuitive equivalent of physical laws. That means they can explain the phenomena but they are not explained themselves in the knowledge system. Metaphorically p-prims in a knowledge system are like atoms in matter. Just like atoms are not the smallest bit of matter in the same way p-prims are not the smallest rather they are smallest piece of observable reasoning unit. Another property is that p-prim can be triggered only in certain situation. The third property is the development of a p-prim where it changes from simple isolated, explanatory system to a piece of larger system to describe a physical law. As another property diSessa describes that different p-prims can have a common abstraction. Thus, p-prims are not context specific; rather they provide the general rule to describe various contexts.

diSessa has identified various p-prims, and some of them are discussed as follows.

Ohm's P-prim: This p-prim comprises the three different elements: an impetus (amount of effort), a resistance, and a result. The relationship between these three elements is such that more effort implies more result and more resistance implies less result. So the basic idea is *more requires more*. The easy description of this p-prim is possible in the context of Ohm's law. For example in order to get *more potential difference it requires more current*. Students hold this type of p-prim as the abstraction of many experiences such as pushing objects. In other words one has to push an object harder if it is heavy and the heavy objects resist the motion. Ohm's p-prim is an example that p-prims are not context dependent. This p-prim can be applicable in electric circuit as well as mechanics. Ohm's p-prim is not misconception; rather it is a bit of reasoning that students can use correctly or incorrectly. For example, they can use correctly in the context where more force is required to accelerate a larger mass. Whereas students may use it incorrectly where student may say that more velocity implies more acceleration.

Force as a Mover: Another example of p-prim is force as mover. The idea of this reasoning is abstracted from the behavior an object moves in the direction of the push. Things go in the direction you push them. In situations such as an object at rest, this p-prim can help a learner predict situations correctly. However, in a situation involving spinning objects applying this p-prim can lead to incorrect predictions of motion by the learner. Force as deflector and force as spinner are other similar type of p-prims.

Dying away: students often hold the idea that induced motion just dies away because of dissipation or friction. An example is the sound of a struck bell that dies out after a while. This idea of type of reasoning leads students to think that *longer means lesser effect*. Students in the experiments involving light often use this type of p-prim.

As mentioned earlier this p-prim also is not a misconception. It depends on the contexts where and when students apply the reasoning. Also an important thing is to note if the resources are activated correctly or incorrectly in a context. When they use the idea of dying away in the case of damped oscillation, they can predict the results accurately. In the contexts of light travel and non-retarding motion of object this p-prim can lead to incorrect predictions about motion and origin of the motion. The p-prim such as *closer means stronger* can be useful in experiments with light where main focus is the measurement of intensity of light but it may hinder the students learning where they are supposed to measure the time instead of intensity.

2.5.2 Facets

As described earlier, p-prims are not context dependent so they are not often observed directly in action. (Minstrell, 1992) elaborated diSessa's idea on students' ways of reasoning in order to understand those ideas in particular physical contexts. He introduced another conceptual resource termed *facets of knowledge*. Facets of knowledge are small ideas that describe a concept of a specific topic, but they are a larger grain of conceptual resources than the p-prim. In addition, being context dependent resources facets are less fundamental than *p*-prims. Usually facets are considered to represent bit of knowledge applied to explain declarative knowledge. A facet can be a generic bit of knowledge, context specific bit of reasoning or can express certain strategies (Galili & Hazan, 2000). An example of a generic bit of knowledge is *more means more*. It is obvious from this example that this type of reasoning are very close to *ohm's p-prim*. *Heavier object falls faster* is an example of context dependent bit of reasoning. In order to find the average velocity of an object students use the strategies of *adding the initial and final velocity and divide that by two*. This example is a strategic facet. For most of the cases, generic bits of reasoning may not be included in facets and regarded as p-prim.

Just as p-prims are not correct or incorrect, so are the facets. Facets are based on the observed phenomena and whatever students observe may not be wrong. For example when a heavy ball and light feather fall together, students clearly see that heavy ball falls faster and they make the idea of heavier falls faster. Therefore, this facet is correct but not applicable in all physics contexts. Students make various symmetrical assumptions in physics experiments even though they may not be correct in all situations. For example, students consider that an explosion results in the formation of bits of equal size.

A facet can be made useful in student learning when they can be used as bridge to the correct facets. Minstrell (1982) used similar kind of strategy for helping students understand the Newtonian idea of a *passive force* taking as an example the force exerted upward by a table on a book. Most of the students do not understand well the idea that the table can exert a force on the book. Students often draw a downward gravitational force in a free body diagram, but do not realize that upward force exerted by the table should be included in their drawing. Most of the students hold the idea that table cannot exert a force but it "blocks" the book from falling. Students on the other hand do not have that kind of difficulty in the contexts of a spring. They can immediately realize that a compressed spring pushes against its compression. Hence Minstrell (1982) used students' understanding of springs as the *anchoring conception* and helped students to build an understanding of passive forces. A series of such *bridging analogies* was then used to help students learn that table acts as a stiff spring.

2.5.3 Coordination class

In order to define associational structures of student understanding and reasoning about physics, diSessa and Sherin have introduced the concept of *coordination class* (diSessa & Sherin, 1998). They have defined coordination class as the systematically connecting sets of strategies to get information from the world. In terms of the size of knowledge structure, p-prim is at one end of the spectrum, whereas the coordination class is at the other end. A coordination class is a group of large and complex systems that can constitute a model of a certain type of scientific concepts. Coordination class can be structured into two parts, the first one is *readout* *strategy* and the second is *casual net*. *Readout strategy* is a set of resources that changes information gained by observation into meaningful and relevant terms. A *causal net* is the set of relevant inferences drawn about information that is not directly or easily observable. The inference is therefore drawn on the basis of the ideas that students already make from the other information in directly observable contexts.

Wittmann used the idea of coordination class in the analysis of student reasoning about waves. (Wittmann, 2002) His research findings indicate the difficulties that student have in understanding waves in string. He reports that the students' difficulties are because of their misapplication of resources and leads to thinking of waves as objects. So he called *object* a *coordination class*. When students learn about wave, they have some expectation and strategies for reasoning and obtaining information. If they think wave as an *object,* then they obviously expect properties different from waves. In doing so students go through various strategies such as looking, touching, and hitting to get the information that is relevant to the information about an object.

2.6 Conceptual Change

Physics education researchers have studied various sources of student difficulties in learning physics ideas. The studies showed that many of the students' difficulties originate from their reasoning resources and some are from their everyday experiences (diSessa, 1993; diSessa & Sherin, 1998; diSessa, 2002; Minstrell, 1992). Through the findings of the studies, they help students to make transition from low level reasoning such as intuition to high level scientific reasoning. In order to help students make the conceptual change, an instructor has to challenge both the reasoning-based and experience-based difficulties. A majority of research on conceptual change has been confined to achieve mainly two goals (Posner, 1982). The first goal is to uncover students' preconceptions about a particular topic or phenomenon; the second is to find out various techniques to help students change their conceptual framework such as preconceptions. A large body of literature is devoted to discussing student's pre-conceptions and conceptual change (Duit, 2007).

Constructivism in its many forms has become an accepted theoretical framework for describing and researching conceptual change among many physics education researchers. Much of the work done on conceptual change is inspired from Piaget's work. The idea of assimilation, which is a key to conceptual change, has become identified with Piaget's constructivism. Disequilibria and accommodation are the major routes in conceptual change. The first of them is the assimilation where a new experience fits into the existing mental schemes. New information is acquired in the context of an existing schema, without altering that schema. The second is the accommodation where the mental scheme changes when it is unable to explain one's new experiences. The third is the reconstruction and this situation arises when merely tuning an existing schema cannot accommodate new information, it results in the creation of new schema.

Different views on conceptual change have been proposed. As viewed by Vosniadou, conceptual change is a model synthesis process in students' minds. (Vosniadou, 2002) Students start with their existing intuitive frameworks and change through a gradual process that can result in a progression of mental models. So this view gives the importance of students' prior knowledge in the learning process. Conceptual change has also been considered as the repair of misconceptions (Chi & Roscoe, 2002). According to this view, students start with naive conceptions. In order to have conceptual change students must be challenged to help them identify their misconceptions and build the correct one. According to this view, misconceptions are the miscategorization of concepts. Through the process of conceptual change, concepts are rearranged to correct categories. Conceptual change according to diSessa is the cognitive organization of fragmented naive knowledge into complex systems in students' minds (diSessa, 2002). As yet another opinion about conceptual change, it is advocated that conceptual change results from changes in the way that students use their conceptual resources in various contexts (Iversson *et al.*, 2002). This view rejects assumptions like restructuring misconception or naïve knowledge in the process of conceptual change.

Posner proposed the conditions to describe how students' conceptual change can be induced (Posner, 1982). So, in order to have conceptual change students:

1. Must be dissatisfied with their existing conceptions
2. Should be aware that the new conception makes sense to them
3. Need to recognize that the new conception must be plausible
4. Should see the possibility of applicability of the new concept in variety of new situation

In the process paradigm shift happens such as from behaviorists to the constructivist. Students do start neither with knowing everything nor with knowing nothing. There is the change in the mental state or mental schema while interacting with the new learning contexts. The induction of conceptual change starts with knowing what students' existing mental schemes are and then providing them new experiences. Cognitive conflict or dissonance (Festinger, 1957) strategies make students challenge their prior resources or experiences. A challenge of students' prior ideas leads them to reconstruct their knowledge consider alternative and higher-level scientific ideas. According to Posner et al. (1982), dissatisfaction with the existing ideas motivate students to reconstruct their conceptions. In this research, I have used series of activities to challenge students' prior ideas through cognitive dissonance method. Students then look for an alternative but intelligible, plausible and applicable reasoning or ideas.

2.7 Physical Models as Analogy

In the area of physics (and science in general) teaching and education research a model is considered as a representation of an object, event or idea. This representation creates a vehicle through which the object, event or idea can be conceptualized and understood (Hestenes, 1987). Gilbert mentioned that there are four types of models: mental, expressed, consensus and historical (Gilbert, 1998). In the context of this research, physical model refers to a physical representation that describes various physical phenomena.

Research indicates that students learn scientifically correct ideas by active engagement. (Hake, 1998; Hestenes, 1987) Those studies showed that by making physical models a central feature of the learning process, students are able to show high levels of conceptual understanding. It is argued that students can be helped to progress from concrete to abstract thinking through the development of their models of reasoning through active learning. The analogies and models have been used in science classroom for last few decades as effective instructional strategy (Grosslight *et al.*, 1991; Jarman, 1996; Tregidgo & Ratcliffe, 2000).

The role of physical models is to facilitate active engagement through use of the models as analogies. The other role of the models is to show the students simplified, comprehensible descriptions of concepts. It is reported that in teaching science analogies are used to apply ideas from a familiar concept to an unfamiliar one (Glynn & Takahashi, 1998). While using physical model or an analogy, the model (or analog) serves as the familiar concept and the unfamiliar one as the target. If the physical model possesses features that are also common to the target, students are supposed to draw analogy between them. Analogies on the other hand can help to build meaningful relations between what students already know and what they are setting out to learn (Glynn & Takahashi, 1998).

As a part of the research presented in this dissertation, I have designed several physical models to help students understand physics ideas related to PET. The discussions in the preceding paragraphs indicate that physical model and analogies have been used in science classroom for several years to serve for the purpose of students learning. My effort in this line is to do in-depth student interviews and uncover the profundity of student learning.

2.8 Transfer of Learning

2.8.1 Overview

To make students able to transfer their learning is one of the most important goals in education. We help students to learn physics from classroom and expect that they can use their physics learning or skill and in other contexts (McKeough *et al.*, 1995). The new context could be the physics problem solving or another physics topic. We want them to go beyond that and apply it in other discipline and also in their future professional life.

Transfer of learning has been classified into different categories. One of the categories is concerned with whether the learning in one context improves performance in some other context or impacts it negatively. (Perkins & Salomon, 1992) The former is called *positive transfer* and the latter as *negative transfer*. *Near versus far transfer* is another category. *Near transfer* refers to transfer between very similar contexts. *Far transfer* refers to transfer between contexts that are very different to each other.

2.8.2 Traditional and contemporary view of transfer

Rebello et al. (2005) have categorized different views of transfer. They labeled them as either traditional view or contemporary view. The perspectives of various researchers in the field of transfer of learning (Adams *et al.*, 1988; Bassok, 1990; Brown & Kane, 1988; Chen & Daehler, 1989; Lochhart *et al.* 1988; Nisbett et al., 1987; Novick, 1988; Perfetto, 1983; Brown, Bransford, Ferrera, & Campione, 1983; Reed, 1993; Reed *et al.*, 1974) are placed in the traditional side. These researchers mainly focus on whether students are able to apply a particular type of problem solving strategy learned in a context to other contexts. Within this perspective researchers pre-define the concepts that students should transfer. These studies demonstrated that transfer is rather rare.

Rebello et al.(2005) also believed that transfer of knowledge and learning occurs in our everyday lives even without our consciously thinking about it. They find that there is a large body of transfer literature that supports their claim that transfer is ubiquitous (Bransford & Schwartz, 1999; J. G. Greeno, J. L. Moore, et al., 1993; Lobato, 1996). Rebello called these perspectives as the contemporary views of transfer. The following is the discussion of some of the perspectives.

Lobato (1996) argues that researchers should not limit themselves by deciding a priori what students should transfer from one situation to another rather they should be more flexible to see from student's perspective to find out what students do transfer to another context and more importantly investigate the process of transfer and the factors that influence it. Along the line of this perspective it is very useful to understand the processes and mediating factors of transfer when it does occur. Such factors in turn give researchers and teachers new insights into the kinds of interventions they need to design to facilitate student transfer in situations where it does not naturally occur.

Greeno et al. have considered the socio-cultural aspects of transfer (Greeno *et al.*, 1993). Their efforts build on (Lave & Wenger, 1991) ideas of "situated cognition." They acknowledge the fact that transfer is influenced by the other external factors such as interactions with the environment as well as social interactions with peers or the teacher. Unlike researchers with the traditional views (Anderson & Thompson, 1989; Gentner, 1983; Holyoak & Thagard, 1989) who considered that transfer is the creation of schema in a learning context and mapping that to the transfer context Greeno et al. argue that this process can not occur most often. Instead of focusing on schema they focus on activities that the learner performs while engaged in learning task. The learner becomes aware of both the physical as well as socio-cultural aspects of the learning situation and then brings these aspects into the transfer context while solving the problem.

Transfer has also been viewed in terms of *preparation for future learning* (Bransford & Schwartz, 1999). Based on this perspective, the researchers focus on whether and how students learn to solve the problem in the transfer context. In addition to this thought, they have another opinion that people not only *transfer out* of situation to solve problem but also *transfer in* to situations to learn. That means transfer should be looked both in learning and problem solving contexts.

This research is framed under some of the contemporary perspectives in investigating the issue of transfer of learning. The *preparation of future learning* perspective proposed by Bransford and Schwartz is one of the most influential views within this research. I believe that students' skills are well developed in learning situations and that influences them significantly in novel transfer contexts. When looking at how students do in problem solving context, I do not pre-decide what should transfer but rather I examine everything or anything that is transferred (Lobato, 1996). My research involves group-learning activities. In that research context, I consider the socio-cultural aspect of transfer (Greeno *et al.*, 1993) as students construct and reconstruct their knowledge through interactions with other peers or the instructor.

CHAPTER 3 - Methodology and Theoretical Perspective

3.1 Introduction

In this chapter I describe in detail the research design, method, population, instrument and procedures used for data collection. Besides this the philosophical or the theoretical perspectives within which the research project develops will be presented. Based on what I (as a researcher) believe about what can be known (ontology) or how it can be known (epistemology) theoretical perspectives will be discussed that influences the methodology.

This chapter begins with the discussion of the challenge of teaching physics of PET to introductory level physics students. A section in this chapter provides detailed descriptions of the research tool, techniques and approaches used in setting up of different stages of the study. Another section of this chapter takes the discussion further by the detailed procedures used for data analysis. It also provides the theoretical perspectives that suggest ways to gather data about a phenomenon and analyze it. In yet another section, I present the pedagogical framework that leads to the development of teaching activities.

3.2 Instructional Challenge in Teaching PET in Introductory Physics

Various physics concepts related to key ideas of positron emission tomography are included in the introductory level physics courses. Momentum conservation and speed-distance relations appear in the second or third chapter of most of the introductory level physics textbooks (Giancoli, 1997; Nelkon & Parker, 1995; Young & Freedman, 2003). On the other hand modern physics ideas such as radioactivity and photoelectric effect are in the second semester of the course and appear near the end of the textbooks (Giancoli, 1997; Nelkon & Parker, 1995; Young & Freedman, 2003). The mass-energy relation and electron-positron annihilation are the ideas that appear in texts but very briefly.

There are mainly two challenges while helping introductory level college students understand physics of positron emission tomography. The students should be able to identify that the PET process involves ideas such as momentum conservation and speed-distance relationship. They also need to know that various modern physics concepts are involved in the process. The first issue is rather easy to handle because students can be helped in the physics content that they are already familiar with. We only need to help them identify and apply such concepts in PET process. The second challenge is much more severe because students in the introductory level physics class do not feel comfortable when they first hear terms such as positron, annihilation, mass energy equivalence and gamma rays (Yeo et al., 2004). It is even more difficult when they see those terms in a context that they are not familiar with. So on one hand the students should be taught about the modern physics ideas and on other hand they should be helped to apply such idea in a novel context. This indicates that a negotiation should be made while teaching such ideas in context of PET.

One way of teaching could be to help them learn every aspect of a particular physics concept and later ask them to apply relevant ideas to PET. The second approach is to concentrate on only those aspects of the physics concept relevant to PET. For example *gamma ray* is one of the ideas that appears during the discussion of PET process. The first approach emphasizes helping students understand every aspect of gamma rays. Alternatively, one could just concentrate on momentum conservation and speed of gamma rays ignoring the rest of the features of gamma rays which are less relevant to image formation in PET. This research project adopted the second approach because the first approach demands high cognitive load (Yeo et al., 2004) and frustrates students.

Constructivist teaching strategies (Driver, 1995) help students learn the abstract physics ideas by building on what they already know. Instead of directly lecturing or demonstrating the process to students they are provided interactive physical analogies resembling some portions of PET. Students learn by active engagement using hands-on activities which help them grasp the working process of the device (Hake, 1998).

3.3 Research Setting

The study focuses on the introductory level physics students' learning and transfer of physics ideas. The study was conducted at the main campus of Kansas State University, Manhattan, Kansas. The university enrollment is over 23,000 including undergraduate and graduate students. The students body comprises students from all 50 states and more than 90 countries.

3.3.1 Participants

The participants of the study were chosen to meet certain criteria. The overarching goal of the research project was to design research-based instructional modules for pre-medical or pre-veterinary medicine physics courses. The study was therefore designed to include those students enrolled in a physics course for pre-medicine or pre-veterinary medicine majors. However, before the target audiences were invited for the participation in the research, I did two preliminary studies.

In the early stage of the research physics education research experts were requested to participate in a study. The experts were surveyed and interviewed regarding the pedagogy and student learning difficulties. The main reason for this effort was not only to establish an idea about student learning and learning difficulties, but also to validate the research protocol for the target audience.

Research protocol and teaching were then tested in *Contemporary Physics*, a physics class of slightly higher level than the course taken by the intended audience. About 30% of the students taking this course are future high school physics teachers. The goal of this course is to make the students aware of the microscopic physical world that is the development of twentieth and twenty-first century physics. Students are helped to develop ideas about physical models used in science. In addition, they are facilitated to apply the ideas in practical application.

After the preliminary studies, the major study of the research was carried out. Students from *General Physics*, an algebra-based introductory level physics course, were invited to participate. Most of the students enrolled in this course already have a background of high school physics. Students majoring in life sciences such as biology, fishery, animal science and industry enroll in this course. Significant portions of students in this group are pre-medicine and pre-veterinary medicine majors. The objective of the course is to help students obtain the broad idea to analyze the natural phenomena, understand the world contexts, explain the technology, and calculate numerically the interesting quantities. Students enroll in lecture, lab and recitation separately. Lectures meet two times a week each for about one hour, laboratory class meets once a week for two hours and recitation is one hour long and meets once a week.

It was also important to choose a suitable time during a semester to conduct the study. I preferred to invite students to participate at that time of the semester when they already covered the kinematics chapters from the course. That consideration was very important since I was interested to see how students build upon ideas from what they already know from their physics classes.

3.3.2 Invitation to Participants

For the preliminary study, in spring of 2005, I e-mailed a request to the Kansas State University physics education group members with a set of questions requesting them to give comments, suggestions and feedback on the questions. The questions were about student understanding of radioactivity with an emphasis on application to medicine. The participants were asked to use their own education research or teaching experiences to respond to the questions. In all, 12 people responded to the request, of whom four were women. All women participants were graduate students. The eight male respondents included four graduate students and four postdoctoral research fellows. After a week, another e-mail was sent to the participants requesting that they participate in individual interviews to tell more about the questions to which they responded. Five of them were interviewed.

In spring of 2006, an invitation was sent to the students of General Physics class by e-mail. I was very careful that the participant sample included different gender, ethnicity and class performance. Students were encouraged to participate in three different ways: motivating them that they will learn useful things and compensating their time by giving them some money. The participants were offered $10 per one-hour session. It was expected that money would attract students of different varieties in terms of their knowledge. I went through the similar procedure when I conducted teaching interview with groups of students during Fall 2006.

3.3.3 Ethical Consideration and Institutional Review Board

The current study involves human subjects, and ethical considerations are important. The main ethical concerns include gaining consent from the participants (Appendix A), protecting participants from the harm, keeping the information confidential, and accuracy of reporting. In order to get the consent from participants they were informed about the study. They were assured about the confidentiality of the data. Their right to discontinue their participation at any time was stated. Participants' right of confidentiality was maintained by identifying data with pseudonyms. They were assured that their responses during the participation would not affect their academic development and self esteem such as course grade and instructors attitude towards them. Accuracy of the data interpretation was another important consideration taken along this line. I regularly asked students after each session to make sure if I understood accurately what they said during the interviews. While analyzing the participants' information, special attention was taken so that the data was neither fabricated nor omitted.

In order to get permission to conduct the research, I completed the training modules provided by Kansas State University IRB board. Final ethical approval to carry out work was granted by the board after the completion of training modules. The research began only after getting the consent from the board.

3.4 Overview of Research Plan

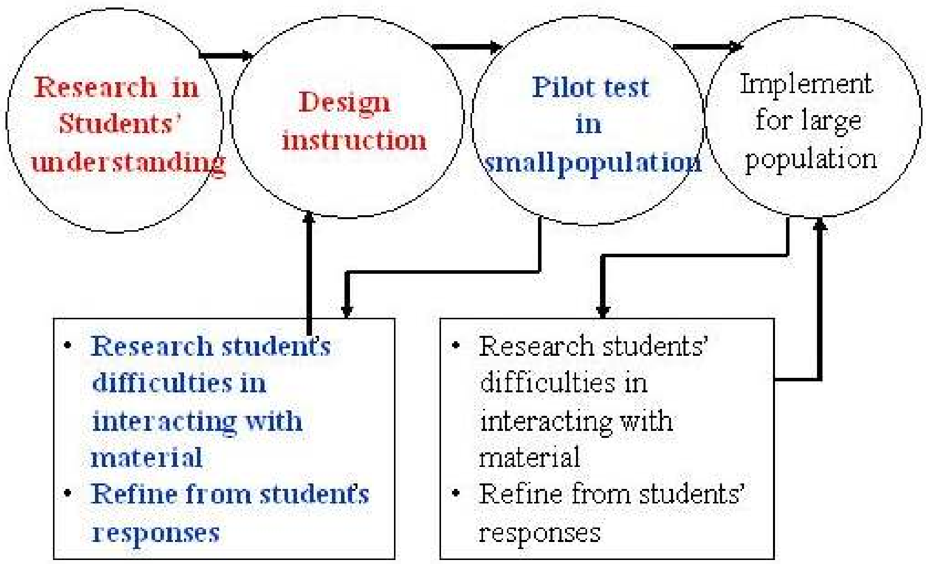
This research was carried out in three phases. The purpose of the first phase was to develop teaching activities. This also served to design the research protocol for the second phase of the research. Experts were interviewed in this phase to know their views about introductory level physics course regarding the emphasis on the application of physics concepts. Students' test and laboratory scripts were also used as data sources in this phase of the research.

The second phase of the study involved deeper understanding of students' learning and learning transfer. Several scaffolding activities were designed and used to help students retrieve and construct their understanding of several physics ideas relevant to positron emission tomography. How the conceptual change (Ivarsson et al., 2002) occured when students' prior ideas are challenged by cognitive dissonance (Festinger, 1957) method was also monitored. In addition to this, student learning transfer (McKeough et al., 1995) was studied in this phase of study.

Students' learning in groups was the main feature of the third phase of the study. The areas of investigations in this phase were the group interaction and peer scaffolding (Bonk & Cunningham, 1998; Bruner, 1966; Bruner, 1984; Vygotsky, 1978).

Different phases of the study can be summarized with the help of Fig 3.1. The first phase of the study includes research in students' understanding and design instruction which is shown by the red texts in Figure 3.1. The cycle of a pilot test in a small population, refining the material from the test and redesigning the activities had been the concentration of the second and third phases of study which is shown by the blue texts in Figure 3.1.

Figure 3.1:Model of Research and Curriculum Designing Used in the Study



Different methodological approaches were used at different stages of the study. In the first phase mainly mixed approach such as surveys and qualitative interviews were used because there was no hypothesis to test at this phase. Data were collected from various sources such as students' tests, laboratory reports, and experts' interviews. On the other hand, in the second and third phase, a phenomenological approach was adopted.

3.5 Philosophical Perspective

The task of this research was to understand the students' perception and construction of knowledge about different phenomena. The students were helped to construct meaning during the interaction with the teaching activities, researcher and their peers. The research emphasized the methodology that facilitates acquirement of multiple perspectives from participants. This section describes the theoretical assumptions made to investigate the issues.

Four dimensions of the assumption about understanding social reality and research have been identified (Cohen & Manion, 1994; Cohen *et al.*, 2000). These considerations significantly affect the methodology and, consequently, methods used in data collection, interpretation and generalization. The four dimensions of assumption are discussed below.

3.5.1 Ontology

The first assumption is ontology, which is the theory of objects. Nominalism and realism are the two dimensions of ontology. *Nominalism* is the view that reality exists only in particular objects and for this perspective social reality is relative, and the social world is mainly names, concepts, and labels that help the individual structure reality. These labels are considered as artificial creations. On the other hand, *realism* considers that universal concepts tie different realities together. It views that the real world has hard, intangible structures that exist irrespective of our labels. The social world exists separate from the individuals' perception of it. The social world exists as strongly as the physical world (Bullock & Trombley, 1999). This implies that the nominalism is more subjective description whereas realism is a more objective description of reality.

This research seeks to find the variation of thoughts among the individuals and look for the reality within an individual or at most in a group. Besides this, the research goal is to look for explanatory results rather than the predictive results. In that sense, I regard that the research is guided more by nominalistic ontological assumption.

3.5.2 Epistemological Assumption

The epistemological assumption focuses on analyzing the nature of knowledge, means of production of knowledge and forms of knowledge. Epistemology has been described as the philosophical theory of knowledge, which seek to define it, distinguish its principle varieties, identifies its sources, and establish its limits (Bullock & Trombley, 1999). Based on the work of Burrell & Morgan (1979), Cohen et al. (2000) have introduced two dimensions of epistemological assumption. One is positivism and the other is anti-positivism.

Positivism views that all true knowledge is scientific. In other words, it is hard, objective and tangible. Based on this perspective one can seek to explain and predict what happens in the social world by searching for patterns and relationships between people. Burrell and Morgan show that following this philosophical tradition one can develop hypotheses and test them, and assume that knowledge is a cumulative process. This views the researcher's role as an observer like that of a natural science researcher. On the other hand anti-positivists view the knowledge as personal, subjective and unique to individuals. They reject that observing behavior can help one understand it; rather one must experience it directly. They disagree with the idea that social science can create true objective knowledge of any kind. Researchers in this dimension are considered not only as an observer but also as an insider and therefore anti-positivists reject the researcher's approach as natural science researcher.

While designing this study, it was very crucial to choose one of the dimensions of epistemological assumption. Despite the fact that the research is in a discipline of natural science, it was very hard not to incline towards anti-positivist side. As a researcher, I was not just observing the hard facts and results of the study, but I was fully immersed with participants while gathering data. However, while analyzing data I was looking for the hard facts, rules and trends in the data. This shifted me towards the positivist side during this stage. Overall, in the continuum of positivist and anti-positivist, I was slightly towards the anti-positivist side.

While designing and conducting research, it is important to consider what students think about knowledge and learning. In earlier discussion, the focus was only on researchers' epistemological assumption. About physics classes students might have a belief that physics learning is memorizing the facts, and a teacher is the information transmitter. Awareness about that kind of students' epistemological belief can provide a researcher a perspective on how to carry out a research. In a conventional view, "unitary ontology" (Hammer & Elby, 2000) has been used to describe the students' context independent set of epistemological beliefs. Hammer *et al.* (2005) have brought up the manifold ontology description of context dependent epistemological resources. According to this view, learners operate in different epistemological modes depending upon the context rather than having a set of epistemological beliefs consistent across various learning situations. A learner may invoke a resource and consider that physics knowledge can pass from the source to recipient (*Knowledge as propagated stuff*). Some learners activate their resources such that they regard their mind as the source of knowledge (*Knowledge as free creation*). On the other hand, some learners could believe that their knowledge is inferred or developed from other knowledge (*Knowledge as fabricated stuff).*

In this study, while looking at students' learning and transfer of learning, I have focused the kinds of epistemic resources students activate during their participation in the research study. It was one of the areas of interest to see how the activation changed in different learning contexts.

3.5.3 Human Nature

The third assumption concerns human nature of social reality. This assumption has two dimensions, namely voluntarism and determinism. Burrell & Morgan (1979) summarize the difference between voluntarism and determinism by a statement: if a researcher views that human nature is determined by their environment the researcher is considered determinist, or if he or she believes that people have "free will" and control their environment, then the researcher is considered using voluntarism philosophical perspective.

Several setting for this research emphasizes students' active engagement with learning and researchers role in helping them to build on what they already know. It is considered that students bring pre-conceptions based on their prior experiences. The society and culture have a vital role in determining what students bring and use in new contexts. Even when students are learning new physics concepts, they rely on what they learned from their social environment. In this sense I regard that this research has philosophical bias towards determinism.

3.5.4 Methodological

The fourth set of philosophical assumptions is about the methodology of research and has again two dimensions. The first one in *ideographic inquiry* which focuses on "getting inside" a subject and exploring their detailed background and life history. In order to conduct the study researchers involve themselves with subjects' normal lives, and look at diaries, biographies, and observation. The second dimension of this assumption is known as *nomothetic inquiry*. Researcher guided by this philosophy rely more on the scientific method, and hypothesis testing. They use quantitative tests like surveys, personality tests, and standardized research tools.

For the current research, we do not go beyond what and how the participants performed during the interview or tasks. Even though we make various speculations about their prior understanding or ideas but not about their normal lives or biographies while analyzing the data. In this regard, I view that this research is not close to ideographic inquiry. By the rule of elimination, the study is more or less nomothetic inquiry. However, the study was not quantitative per se.

3.6 Theoretical Perspective

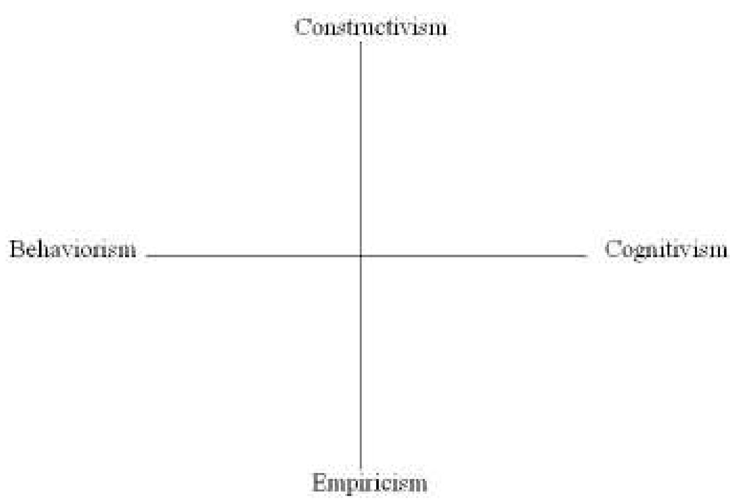
This section describes the theoretical approach underlying the study. Several theories such as cognitivism, constructivism and transfer of learning were used to guide the study. The approaches not only helped in selecting the research design, participants, and data collection but also during data analysis and discussion of research findings. The aforementioned theoretical perspectives are described below.

Eight meta-theoretical belief system (MTBS) has been introduced to explain the theories of learning and development (Byrnes, 1992). The theories describe the nature of knowledge, mental representations and origin of knowledge. Out of three dimensions of learning and development (Byrnes, 1992), I will describe two dimensions, shown in Figure 3.2 , that are relevant to this research.

3.6.1 Cognitivism

The first dimension of learning theory explains of theories about the nature of behavior. Behaviorism falls at one end of the continuum and cognitivism at the other end. Cognitive theory was used in this research; however I am explaining briefly behaviorism and then describe cognitivism in more detail.

Figure 3.2:Dimensions of Learning Theories



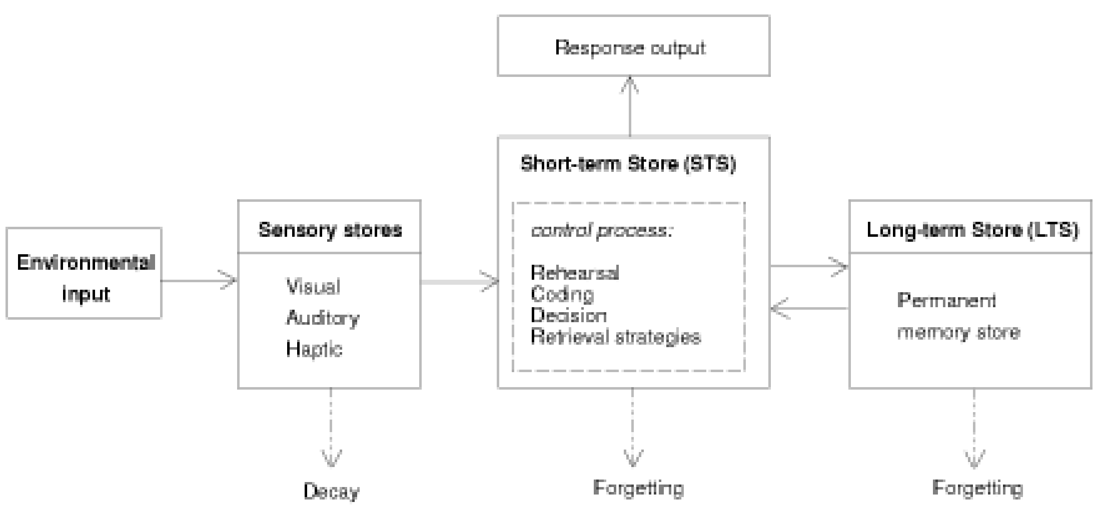
The theory of behaviorism concentrates on the study of behaviors that can be observed and measured (Good & Brophy, 1990). This theory considers that for a scientific study only observable things should be the focus. Behaviorists consider learning as the connections between stimuli and responses (Skinner, 1953) and measure learning by change in behavior. Behaviorists are naturalistic so they consider the material world as the ultimate reality, and claim that everything can be explained in terms of natural laws.

Cognitivism, which is at the other end of the continuum of nature of behavior, is a theory of learning and instruction that focuses on the mental processes rather than the observable behaviors. It regards human learning not as the acquirement of new information but as a complex process that involves thinking, receiving, storing, integrating, retrieving, and using the information. The main principle of this theory is that learning occurs when information becomes meaningful to the learners. It focuses on plans, goals, schemata operations, and inferences rather than stimuli-response associations (Bruning *et al.*, 2004).

As mentioned earlier this study uses cognitivism as one of the research theories. I am interested in the cognitive tools students use when they learn and transfer physics ideas as well as in cognitive processes to understand dynamics of learning. The discussion below is focused on cognitive processes that involve how students receive, store, integrate, retrieve, and use information.

The modal model (Atkinson & Shiffrin, 1968), or multi-store model, is still considered as one of the most influential models to describe the memory system and cognitive processes. The role of the memory is to process the information, which involves the process of acquiring, retaining, and using information. The sensory stores process information coming from the outside environment. Instead of keeping all the information, the brain constantly goes through filtration of the information. The filtration is highly influenced by learner's motivation and beliefs about learning and prior knowledge (Redish, 1994). The information then passes into the short-term memory store and is processed.

Figure 3.3: The Model of Human Memory Proposed by Atkinson & Shiffrin(1968)



The information that is relevant to the learner's goal is finally transferred into the long-term memory where it is stored indefinitely. The stored mental associations of the information form a pattern known as schema (Woolfolk, 2001). Knowledge is organized in the memory and is labeled as declarative and procedural (Bruning et al., 2004). The process of storing information in memory is *encoding* and the process used to access the information from long-term memory is *retrieval*.

This research adopts the cognitive perspective of learning that employs information-processing ideas. Along the lines of this view, I assume that learning is a process of relating new information to previously learned information. Through this study, I tried to understand what kind of knowledge pattern students have and how they change it. After providing different activity- based learning experiences I investigate how students assimilate and accommodate new information in their existing schema. In addition, with the aid of cognitive dissonance activities I explore the students' equilibration (Piaget, 1964) process. Students' information encoding in one context and its retrieval in another context were also relevant in this research while investigating transfer of learning.

3.6.2 Constructivism

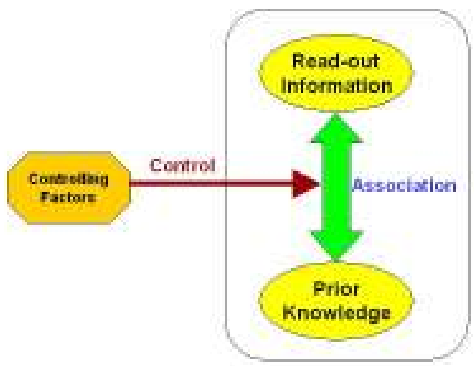
The second dimension of learning theory pertains to the issue of the origin of knowledge (Byrnes, 1992). Empiricism and constructivism are two components of this dimension. Empiricism is the view that knowledge is acquired through exposure to the world. Whereas the essence of constructivism is that knowledge is progressively created or invented by individual. The detail of constructivism is already presented in Chapter 2 so I would refer that chapter to see the theory and different views about constructivism. Constructivism is introduced in this Chapter in the context of the second dimension of learning theory.

I have used both the Piaget's and Vygotsky's perspectives of constructivism in guiding the research. Just like Cobb pointed out, I view that these two perspectives do not have much fundamental differences at least in context of my research (Cobb, 2005). The learner must eventually internalize knowledge constructed through these different kinds of activities no matter if it is socio-cultural or sensory-motor method. Despite this assumption, I am more focused on Piaget's view during the individual interview phase and Vygotsky's view of zone of proximal development in the group interview.

3.6.3 Transfer Framework

In Chapter 2, I described transfer of learning and also presented different transfer perspectives. Based on various contemporary perspectives of transfer and cognitive theory of learning, the Physics Education Research Group at KSU has developed a transfer framework (Figure 3.4), and which guides this study (Rebello et al., 2005). It is founded on the two-level framework proposed by Redish (2004). The first level refers to the association between knowledge, whereas, the second level refers to the factors that control the association.

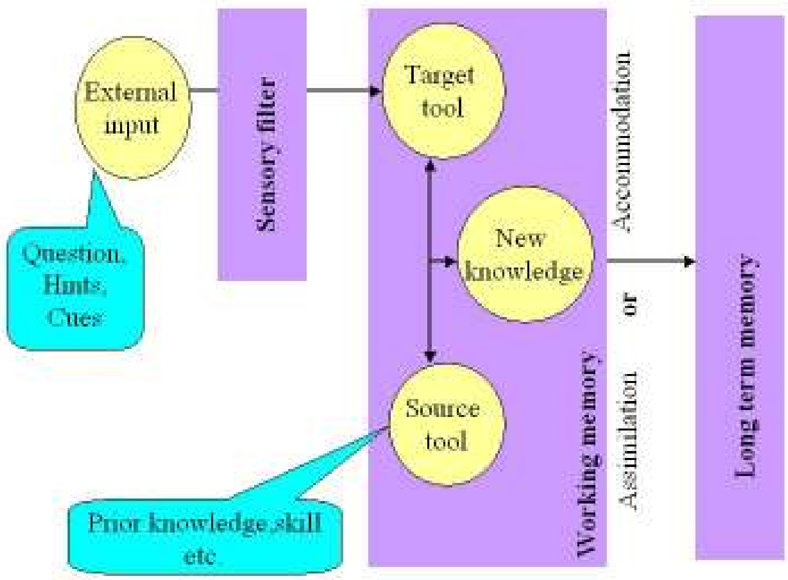
Figure 3.4: The Two Level Framework



This framework views the transfer as the dynamic association between different cognitive resources. Learners' epistemic modes such as motivation and their views about learning control the resources. According to this model of transfer, researchers instead of focusing only on productive association look for all possible associations made by students.

The Figure 3.5 describes an overview of cognitive process involved in the dynamic creation and knowledge transfer. Mainly four elements are involved in the process. The first is called *external input* which can be provided through questions, hints, demonstrations and pictures. When students are learning in a group, they can also get clue from their peers which can be another form of input. Another element of the process comprise *target tool* which is created by the student when the external input passes through the sensory filter. The third element involved in the process is the *source tool* which is the knowledge or reasoning held by students due to prior experiences. In this framework, the dynamic creation of association between the source tool and target tool takes place in working memory. The fourth element is the created *new knowledge*. If the student finds the answer or the created information meaningful, then assimilation or accommodation in the existing schema takes place in the working memory and eventually stored up in the long term memory.

Figure 3.5: Mental Processing Taking place in Transfer



The third element as described above is the main idea of transfer within this framework. In this research the students' interview transcripts were analyzed to determine the external inputs, activated source tools and controlling factors of the activation. While investigating students learning transfer, I looked at the association that students make. However, I did not make a value judgment on whether or not these associations are scientifically correct. I adapted a neutral stance with regard to these associations and attempt to examine all possible associations that a student makes.

3.7 Methodological Perspective

3.7.1 Qualitative Research Method

The research method used in these frameworks should be such that the inquiry is more naturalistic and highly interactive rather than experimental. The goal of the research under these frameworks is to uncover embedded meanings through words and text, and describe participants lived experiences in their own words with less emphasis on quantifying the results.

As mentioned by Strauss & Corbin (1998) the qualitative research methodology produces findings that do not arrive by means of statistical procedures or any kind of quantification measures. One of the features of the qualitative data is that not only the researchers but also readers perceive that the data conveys a full description of phenomenon (Lincoln & Guba, 1985). Qualitative research provides typically detailed information about participants' experiences in relation to the phenomena (Stake & Easley, 1978) and that makes the description of the findings meaningful.

Five different traditions of qualitative research have been introduced (Creswell, 1998) which are known as biography, case study, grounded theory, phenomenology and ethnography. In the preliminary research stage no specific tradition was followed therefore I would rather call that method as simply a qualitative method. During the major parts of investigation a phenomenography approach was used. I describe phenomenology first and then phenomenography because the latter builds within the framework of the former.

3.7.2 Phenomenology

Phenomenology itself is not a research method rather it is a theory that guides the research methods. As discussed in the earlier section of philosophical perspectives this research is more inclined towards the anti-positivist side. One of the features of phenomenology is that it opposes the positivism which is accepted by most of the natural scientists. One of the goals of this research was to uncover students' cognitive origin of learning difficulties.

Phenomenologists try to reveal the human consciousness not only about the objects in the natural and cultural worlds, but also ideal objects, such as numbers (Creswell, 1998). The purpose of this research is to make students' conscious life evident. Phenomenology is the empirical study of the limited number of qualitatively different ways in which we experience, conceptualize, understand, perceive, apprehend etc. These experiences, understanding etc. are characterized in terms of categories of description.

In this research, ideas of *phenomenological reduction* and *intersubjectivity* were used to gather and analyze the data. The viewing of phenomena without prior judgment or assumption is *phenomenological reduction.* That is why in analyzing the interview transcripts codes emerged from students' ideas without my preconceptions. By *intersubjectivit,* the researcher has access to the experience of others through his/her own experiences.

3.7.3 Phenomenography

Qualitative researchers attempt to examine the participants' experiences, feelings and perceptions without distorting the participants' ideas (Patton, 1990). A phenomenographic approach was found relevant to this study to describe how students' perceive the learning contexts and the variation of their perceptions.

Phenomenography is designed to answer questions about the process of students' thinking and learning. The purpose of this tradition is to investigate how students interact, interpret, understand, perceive or conceptualize and experiences with phenomena. This approach is used to see the variations in the data while different participants interact with the same phenomena. There is the use of categories of description, identifying conceptions and looking for their meanings and relationship between them.

The conduction of research using this tradition comprises various steps. The interview is taken followed by identification of the distinct categories. Phenomenographic categories are mixed with the field notes taken during and after the interviews. In yet another step the transcripts of several participants are examined looking for both the similarities and differences among them. Finally, in order to determine if the categories are sufficiently descriptive, the transcripts are re-examined.

In the data analysis stage, my research utilized the method described by Colaizzi (Cohen & Manion, 1994) in the following seven steps.

1. Each participant's interview transcript is read to acquire his/her inherent meaning.
2. The significant statements are extracted and underlined.
3. Meanings are formulated from the significant statements
4. Meanings are organized into themes, themes form clusters, and clusters form categories.
5. Participants' feelings and ideas contained in themes are described analytically.
6. Essential structure of phenomena is formulated.
7. The formulated meanings are taken to the participants for the validation check.

3.7.4 Credibility

In positivist inquiry, internal validity refers to the extent to which the findings accurately describe reality. But as Lincoln & Guba (1985) pointed out it is not possible in qualitative research tradition because one needs to know the *precise nature of that reality* for the validity test and if one knows this already there would be no need to test it. The essence of qualitative research is to assume the presence of multiple realities and to attempt to represent these multiple realities adequately. The findings in such circumstances are therefore tested by means of credibility.

To test the research findings researchers need to be aware of richness of the data and his/her own analytical abilities rather than focusing on sample size (Patton, 1990). Six types of triangulation has been identified for the credibility test (Mertens, 2005). I have used two of them in my research, which I describe below.

Member Checks

One of the ways of increasing credibility of interpretations is to go back to the participants, at the completion of the study, and ask them if the interpretations are accurate or need correction or elaboration on the findings (Mertens, 2005). Some researchers work together with the participants to plan, conduct, and analyze the results. In the case of my research the study design allowed me to do the verification of my interpretation right from the interview process. Students were asked regularly during the interview if I interpreted their statements correctly. During several activities in interview session and before the end of each activity, I engaged students in discussion to summarize their ideas. I conducted two interview sessions with each of the students. After the completion of the first second session I started analyzing students responses of the session. When they came to the second, I made sure by asking them if I interpreted their statements of first session correctly. Even after the second session, there was a discussion of about 10 minutes before they left, during which I asked them to reflect on the overall activities. My interpretations about their responses were the main topic of discussion during that time.

Peer Debriefing

As another way of triangulation to address credibility, I made segments of the raw data available for others to analyze. Physics education researchers at KSU were involved in this effort. Besides this, I engaged in discussion with my advisor about my analysis and conclusions after we saw the videos of students' interviews separately. The other peers in my research group were also involved in the debriefing process when I talked about my research in seminar presentations, group meetings and informal talks.

3.7.5 Transferability

The generalization of findings in different settings is the essence of the external validity in the positivism paradigm. In the qualitative research paradigm, it is difficult to predict that the working hypothesis will be *transferable* to other situations. It mainly depends on the degree of similarity between the original situation and the situation to which it is transferred. The researcher cannot specify the transferability of findings. The readers need to decide based on the description on information if the findings are applicable to the new situation (Lincoln & Guba, 1985). In my research, I tried to maintain the similar contexts in different teaching interview. This in a sense helped to generalize the findings.

3.7.6 Dependability

Dependability in the qualitative paradigm is parallel to the reliability in post-positivism paradigm. Reliability gives the degree of repetition of measurement, and the stability of a measurement over time. Change in the measurement is expected in the constructivist paradigm and is acknowledged by qualitative tradition. This change should be tracked and publicly inspectable (Mertens, 2005). As proposed by Lincoln & Guba (1985), use of *inquiry audit* is a measure to enhance the qualitative research. Within this method reviewers examine not only the product of the research but also the process of the research for consistency.

In the case of my research, I have video and audio taped the interviews to capture the different modes (verbal and non-verbal) in which students convey their explanations of certain aspect of the phenomenon under study. The video was taken such that it captured their gestures and the way they engaged with the teaching activities. However, their face was not captured to maintain anonymity of the participants.

3.7.7 Clinical and Semi structured Clinical Interview

A clinical interview is a structured interview that consists of administering structured questionnaires. Interviewers ask questions (mostly fixed choice) in a standardized manner. Semi-structured interviews are conducted on the basis of a loose structure consisting of open-ended questions that define the area to be explored. In the context of education research, the interviewers or researchers diverge afterwards in order to pursue an idea held by students in more detail. The goal of a qualitative research interview in education is to discover what the students already know. So it takes a snap shots of students' knowledge and their understanding.

In this research, I used the semi-structured clinical interview method in the preliminary stage. Physics Education Researchers at KSU were interviewed by using an interview protocol. It was considered important to understand their views on the current curriculum and pedagogy. One of the physics concepts, radioactivity, involved in the PET process was the focus of the interview. However, I tried to cover their views on student understanding of medical application of physics such as PET. The interview protocol consisted of a fixed set of questions related to physics teaching in medical contexts and the same set was used for all the participants. However, depending upon their responses I further probed at certain points. The typical time for the interview was about 30-45minutes. The interview was audio taped so that I would not miss anything.

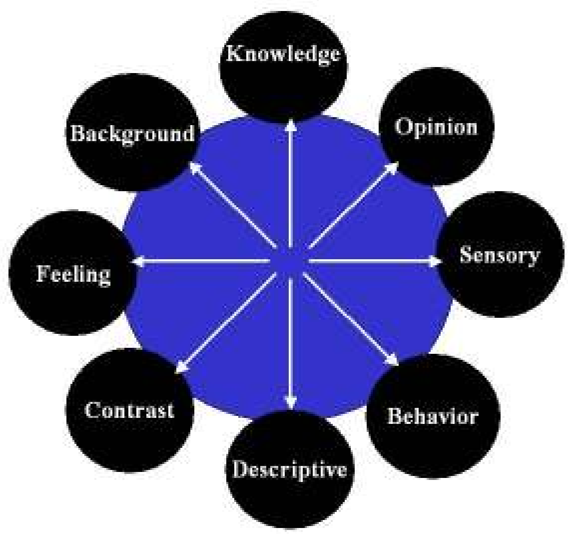
3.7.8 Teaching Interview

Teaching interviews were used in the major parts of this research. Unlike the goal of traditional clinical and semi-structured clinical interview where information about a students' current thinking on a topic is elicited, the aim of teaching interview is to uncover students learning processes. The teaching interview is regarded as mock instruction (Engelhardt *et al.*, 2003) where the interviewer plays the role of instructor and students are engaged in a laboratory-like learning setting. Students engage in the activities, and the researcher asks questions regularly to help build their understanding of relevant ideas. Whenever necessary the interviewer provides scaffolding and sees how students progress. This setting is very close to the Vygotsky's constructivist learning model (Vygotsky, 1978) where students learning is influenced by socio-cultural influence and scaffolding. Students learn with the help of a more knowledgeable other, the interviewer. One of the salient characteristics of teaching interview is the intervention by the researcher into the students' learning processes. The outcome of the interview is qualitative rather than quantitative data.

The teaching interview is more commonly known as teaching experiment (Katu *et al.*, 1993; Komorek & Duit, 2004). Komerok and Duit (2004) used the teaching experiment as a tool for the investigation of students' ideas about non-linear system and their idea development with the help of teaching and learning sequences in the interview setting. They identified the method as a research tool as well as an effective technique of development of teaching and learning sequences. Katu et al. (1993) used the teaching experiment strategy to help students develop their understanding of electricity through series of teaching episodes.

I conducted teaching interviews in the second and third phase of my research. A teaching sequence using hands-on activities was developed and used in an individual teaching interview setting in the second phase. Students engaged in active learning by using the activities. My role was a facilitator of learning like a constructivist instructor. However it was more than instruction where I was looking carefully students' ideas first and then their progression. The scaffolding activities were used as mediating factors in their learning process. The results from the second phase of the study provided input for the revision of protocol for the third phase of the study. In the third phase of the research the teaching activities were used in the group interview settings where I engaged two or three students at a time.

Figure 3.6:Types of Question Asked in Students' Teaching Interviews



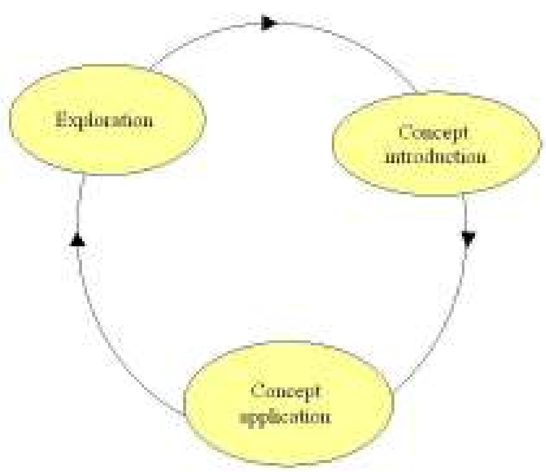
Even though the teaching interview is contemporary research technique, I used the varieties of questions that are recommended for traditional in-depth interview. Minichiello *et al.* (1995) have discussed different types of questions for the purpose of in-depth interviewing as shown in Figure 3.6. I describe below some of them from the list. *Descriptive question* according to them is the one that allows students to discuss their experiences in their own words. *Background questions* are used to get background information of students. In context of my interview, it was used to know their background in physics and their majors. By the use of *knowledge questions,* I tried to understand what kind of factual knowledge that students have in the relevant physics ideas. *Contrast questions* enable researchers to look at how students perceive different situations. *Opinion value questions* are very important in understanding students' epistemological belief. I regarded that asking different types of questions to students about an idea help me in triangulating data analysis in a way. While interviewing the students, I made sure that I asked as many different types of questions as possible. However, I tried to maintain the similarity in the major question set for all the students or group of students.

Aligning with the tradition of qualitative research (Creswell, 1998) I focused on three areas while asking questions. I tried to ask open-ended questions and avoid dichotomous questions. I was also very careful not to ask multiple questions at a time. During the interviews, I was very cautious not to intervene when students were speaking even in some circumstances where they were taking the discussion in some different direction.

3.8: Pedagogical Framework

In developing the teaching activities, which were used in classroom as well as in teaching interview settings of my research, I used learning cycle model introduced by Karplus (1977). This model is within a framework of cognitive development of the learner. It consists of three phases and is guided by the assumption that science learning is a process of self–regulation in which learners form new reasoning patterns through the interaction with phenomena. Piaget's notion of assimilation, accommodation and equilibration are involved during the different stages of the cycle (Piaget, 1964).

Figure 3.7: The Karplus Learning cycle



The first phase of the learning cycle is called exploration in which students learn through their own actions and reactions with minimal teacher guidance. Students explore material freely that leads to questions and they look for patterns through their own involvement with the provided materials. The main goal of this phase of the cycle is to provide a common frame for all students and to raise questions to be answered later. The second phase of the model known as concept introduction is more like the traditional teaching setting where, the concept is introduced and explained. Here the teacher is more active, however, inquiry approach is acknowledged. Finally, in the application phase, the concept is applied to new situations and its range of applicability is extended. Generalization of the application through practice of their knowledge allows them to stabilize new ideas and ways of thinking.

3.9 Chapter Summary

In this chapter, I described the methodology used in this research. Theoretical and philosophical perspectives consistent with a qualitative research method guide the research. Four dimensions of the assumption about understanding social reality and research were discussed. I also mentioned where along the axis of each dimension this research is situated. The research is inclined towards nominalistic view in ontological assumption, slightly towards anti-positivism in epistemological assumption, biased towards determinism in human nature assumption, and more or less leaning towards nomothetic in methodological assumption.

The most influential theoretical perspectives guiding this research are cognitivism, constructivism, and a framework of transfer of learning. This research seeks to describe the students' learning process as a complex mental progression rather than observable behaviors. This research employs the teaching interview method to engage students in the constructivist learning environment. Piaget's and Vygotsky's theory are used to understand students' learning process. A transfer framework guided by the cognitive psychology and consistent with many contemporary views of transfer is used in this research.

Phenomenology and phenomenography are the two qualitative research methodologies used to conduct the research. Colaizzi's steps are adapted to analyze the data, and then a variation is established in students' responses. To increase the credibility of interpretation of findings, this research uses the method of member check where many researchers analyze the data independently. This research also uses the member check to address credibility where students are asked if their responses are accurately interpreted.

CHAPTER 4 - Development of Teaching Activities

In this chapter, I describe the development of teaching activities related to physics of PET. The physics ideas involved in the technology of positron emission tomography (PET) were isolated. Speed-distance relation, momentum conservation, radioactivity, photoelectric effect, mass-energy relations, electron-positron annihilation were identified as the key ideas which could be taught in introductory level physics course.

The first step in this effort was the investigation of the physics education experts' views regarding teaching radioactivity. A student survey was also conducted to structure the teaching material. As yet another step a test was administered in a class. The output of the effort was a set of teaching activities in radioactivity. Teaching activities in mass-energy relation, annihilation and coincidence detection were also developed and tested.

4.1 Radioactivity

4.1.1 Creation and Conduction of Survey

The first round of the study involved the investigation of students' ideas about radioactivity through survey. The goal of the survey was to learn about students' knowledge and experience about radioactivity, one of the key concepts involved in PET. More specifically the students' ideas were investigated in five areas that include students' knowledge of radioactivity, half-life, nuclear stability, positron emission and medical application of radioactivity. The survey questions were mainly adapted from earlier studies on radioactivity done elsewhere (Aubrecht & Torick, 2000; Prather, 2000; Prather, 2005; Prather & Harrington, 2002) with some modifications to give emphasis on the application aspects of radioactivity in other contexts such as in PET. Both the open-ended and objective questions were included in the list of 21questions (Appendix A).

Of the nine physics education researchers at Kansas State University, two participants had never taught radioactivity topic in high school or college. One participant had taught it in introductory level physics laboratory. Rest of the participants had previously taught the topic in different courses. The goal of the survey was to know their views on student understanding and teaching of radioactivity. They were asked to pick the 10 best questions from the list that could be useful in probing student understanding of radioactivity and its application in PET. Along with the survey questions the participants were also asked about the objectives of the survey.

Participants 'Responses on the Survey Questions

The questions were categorized according to the objectives. My main interest was to see what objectives they wanted to emphasize most and how they picked the questions. The objectives were coded as follows.

Objective 1: Radioactivity (KR)

Objective 2: Half-life from graph (HL)

Objective 3: Nuclear stability and decay (ND)

Objective 4: Different types of decay (TD)

Objective 5: Positron emission and medical application (MA)

Table 4.1: Responses on Survey Questions

Participants	KR	HL	ND	TD	MA
1	1	12,13,19,20,21	7,11		
2	1				
3	4	20,21	7	10,15,16,17,18	8
4	1,3,4	12,19,21	7	9,10	
5	1,3,4	12,13,21		10,15,17	6
6	3,4	13,1920	7	9,14,15,18	
7	1,2,3,4	19,20		18	6,8
8	1,4	21	11	15	
9	1,2,3,4	19,20,21		17,18	

The questions chosen by the participants are tabulated in Table 4.1. The participants were assigned numbers to maintain anonymity. Questions from the list were tabulated with each category. In the tables I have entered the question numbers (please see appendix A for the questions).

Table 4.2: Frequencies

Objectives	Objective Frequency	Frequency of individual questions
KR	21	1(7), 2(2), 3(5), 4 (7)
HL	22	12(3), 13(4), 19(4), 20(5), 21(6)
ND	6	7(4), 11(2)
TD	18	9(2), 10(3), 14(1), 15(4), 16(1), 17(3), 18(4)
MA	4	6(2),8(2)

Results of the Survey

The most frequently (22 times) chosen questions from the survey were from the radioactive half-life (HL) category. Knowledge category (KR) stands second (21 times) and types of decay (TD) category come third (18 times). This survey result indicates the nuclear stability (ND) category (6 times) and medical application (MA) category (4 times) were least frequently chosen. This result clearly indicates that most of the teachers immediately think of teaching radioactivity in terms of definitions and then half-life. It is understandable because the introductory level physics texts book and course structure give less emphasis to the medical application of physics. However, it is surprising to note that the participants did not emphasize nuclear stability, which is the reason behind radioactivity.

In terms of questions within each category, questions 1 and 4 of category KR were most frequently chosen--each 7 times. Question 1 is background demographic question that explores students' background of radioactivity learning, whereas question 4 is descriptive type question that investigates students' basic knowledge about radioactivity. Question 21, which is related to radioactivity half-life, was chosen 6 times. Among the least chosen were question number 14 and 16 that are related to the nature of emitted particles during radioactivity. It is interesting to note that the participants just give importance to helping students know the types of radioactivity without helping them understand about the emitted particle or radiation.

4.1.2 Interviews with the Experts

After the completion of the survey an individual interview was conducted with five of the participants. The purpose of the interview was to cross-examine participants' responses and to explore their experiences about student knowledge of radioactivity as well as the instruction of radioactivity in introductory level physics classes. A set of interview questions were developed based on the participants' responses on the survey questions. Though the interviews were guided by a structured question set, each interview was slightly different. In order to focus specific issues the flow of interview was narrowed down or further probed.

Table 4.3: Expert Interview Category Tabulation

Category	Most frequently used terms				
	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Knowledge	Half life (7)	Half life (7), graph (5), definition (6)	Definition, half life, graph	Graph (2), definition (4), half life (7)	Definition
Stability	Not knew stability at college (5)	Not knew stability at college (5)	Decay (4), stability and decay (9)	Unaware of stability (3)	Number of nucleon
Types of decay	Alpha (8), Not heard positron (5)	Alpha (6), beta (5), Not heard positron (2)	Alpha (4), beta activity (3), Positron-electron (5)	Alpha (4), beta (2), gamma (2), positron not known	Alpha (4), beta (3), gamma (1), positron not a beta emission
Application	Medical, electricity (5)	Medical, war, energy (6)	Hazards, (4) treatment	Scary, lead, medical use, atom bomb	Nuclear energy (4), medical use
Teaching strategy	Motivation, examples (3)	Motivation	Application	GM, sample demonstrate	Graph (2), GM (1)

The analysis of data began with listening to the tape couple of times immediately after the interview. Reflective notes were taken after listening the tape. Field notes and the reflective notes provided useful information for the next interview. The main ideas that were noted down in the form of reflective notes and field notes provided the source for data codes. Different codes were then clustered in several categories.

The summary of the categories emerged from the analysis of interview data after the coding process. The terms used by the participants within the respective categories are presented in the Table 4.3.

Interview Results

The interview results are consistent with the survey results. The participants expressed similar views during the interviews regarding their views on the instruction of radioactivity. The themes emerging out within each common category is described below.

1. Knowledge: The interview showed that most of the participants view the importance of inclusion of idea of radioactive decay half-life as one of the main ideas covered in the texts and classroom. They indicated that inclusion of graphs in teaching was rather difficult. They were influenced by their prior teaching experiences on such courses as well as from their learning at undergraduate level.
2. Stability and nuclear decay: Another relevant idea that was frequently used during the interview by the participants was that students understanding in nuclear decay and stability are important while teaching radioactivity. However, they mentioned that they were unaware of this fact when they were students and did not focus in it when they taught radioactivity in class.
3. Different kinds of decay: Most of them mentioned different types of decay without going into further detail. The most frequently used term was alpha decay. Gamma decay was chosen by least number of participants as a type of nuclear disintegration.
4. Positron emission: Very few participants mentioned that they heard or understood this term when they were undergraduate students. Some of them mentioned that students do not know that it is a type of beta decay.
5. Application of radioactivity: It is found from the interview that neither current courses in physics nor the teachers give emphasis to the application of radioactivity in medical contexts. The participants mentioned that they were only familiar with the warfare and nuclear reactors regarding radioactivity.

6. Teaching strategies: The participants mentioned that various everyday life related examples and application aspects of radioactivity could serve as source of students' motivation to learning radioactivity.

4.1.3 Student Test

Based on the results of the expert survey and interviews a set of questions was selected. The questions were used to administer the pretest in a class. The experts' perceived that many of the students are unaware of the medical application of the radioactivity. They also suggested that students' understanding could be elicited if they are given the real world or medical context in the questions. Another part is that many students at this level are not familiar with the positron even though they have heard beta particles. Most of the students consider beta decay as an electron emission. These facts were taken in consideration while creating the test questions for the students. The purpose of this pretest was to understand what students know about radioactivity so that teaching material in the class could be structured. The pretest is comprised of five questions (please see Appendix C).

The test was administered in the Contemporary Physics class in Spring 2005. Several modern physics topics had already been covered in the class before the test was administered. Seven students participated in the test.

I describe the results of the study in different categories below.

1. Radioactivity decay: In response to the questions regarding radioactive decay only three students answered correctly. They were able to bring up ideas of nucleus decay in atomic nucleus. However, most of the students had a hard time describing the reasons for decay. Four students who did not give correct answers when looking at the figure of nuclear decay considered it as a process of collision. In describing the process they used terms such as collision, chemical bonding, fused collision, proton and neutron kicked out, and process taking place in proton. I view this as indicative of the students' unawareness about radioactivity or they immediately related their prior experience of collision with the process represented in the picture.
2. Stability: None of the students who participated in this study related the process of radioactivity with the nuclear stability.

3. Radiation and radioactivity: Most of the students (6 out of 7) believe that a substance becomes radioactive when exposed to radiation as well as when radioactive material is inside human body. This result is consistent with the results of earlier studies (Aubrecht & Torick, 2000; Millar, 1994; Prather, 2000; Prather, 2005; Prather & Harrington, 2002). Students' reasoning as indicated by this study is that if amount of radiation is large then a substance becomes radioactive. One student mentioned that injecting radioactive material doesn't make a person radioactive because the material is not harmful.
4. Half life and decay rate: The students (6 out of 7) did not indicate any difficulty in identifying the number of particle changes in half-lives. However, they expressed ideas of change of mass and volume of the sample with the radioactivity decay. This result is also consistent with earlier studies (Aubrecht & Torick, 2000; Millar, 1994; Prather, 2000; Prather, 2005; Prather & Harrington, 2002). One of the students wrote that atoms are less reactive in less volume and hence less radioactivity. This is an example of the students' use of the resource "more means more and less means less" that I described in Chapter Two (diSessa, 1993). Question 3 and 4 were related to the activity of sample. The students (5 out of 7) who answered question 3 correctly were not able to do question 4 correctly. In question 4 I gave a context where they need to apply their understanding of relating rate of decay and activity of sample.
5. Knowledge on positron emission: The students who mentioned charge conservation (3 of 7) could identify that positron is a positive charge. But nobody mentioned that the emission is caused by beta radioactivity.

As a summary, this study indicates that those students' understanding in radioactivity is similar to reported in the previous studies (Aubrecht & Torick, 2000; Millar, 1994; Prather, 2000; Prather, 2005; Prather & Harrington, 2002). The main conception among the students is the interchangeability of radioactivity and radiation. Students do know the definition of half-life of an isotope but do not know how it is related to the activity of a sample. The particle disappearance idea is held by majority of the students. It is reasonable to attribute this student reasoning to the various textbooks that depict the situation of disappearance of nuclei with nuclear decay. That students were unsuccessful in using the radioactivity in the real context type problem motivates us to design the teaching activities where their understanding can be assessed.

They were found to be unaware of the cause of radioactive decay. In terms of the students' knowledge about positron, more than 50% of them (4 of 7) did not know about positron. Even though 3 out of 7 correctly identified the charge of the emitted particle as positive but did not know it was a positron. The issues revealed from the study were considered in structuring the teaching material of radioactivity, which is described below.

4.1.4 Completion of the teaching activities in Radioactivity

A set of teaching activities in radioactivity was developed (See appendix D) using the learning cycle format (Karplus, 1977). The exploration stage comprises the hands-on activities and a computer simulation. Students explore with the dice activities to understand the exponential decay of a sample. The computer simulation aims to help students explore about nuclear decay. The discussions in the concept introduction phase are built on the activities of exploration phase. During this phase several terms such as nuclear decay, half life, and types of decay and their decay mechanism are introduced. The concept application stage begins with the discussion on applications of radioactivity for various examples in everyday life followed by a brief introduction of PET. Stability and decay curves of several radioactive isotopes are provided, and students are asked to identify the isotopes suitable for positron emission tomography imaging.

4.2 Mass-Energy Relation and Annihilation

4.2.1 The Creation of Activity

Creation of a learning cycle teaching activity of Einstein's mass-energy relation and its application in electron-positron annihilation was the focus of this effort. The created activity (see appendix E for detail) was used in a class, and a test was administered. The emphasis was placed on how students understand the mass-energy relation as a form of energy conservation.

Students were given several examples where a projectile strikes to a nucleus at rest resulting in the formation of product nuclei. Masses and energies of individual particles were provided. They were supposed to note that in the reaction mass and energy are not conserved separately and then establish a relationship between mass and energy. The units and magnitude of constant of the proportionality were not, however, the focus of this stage. Einstein's mass - energy relation was discussed in the concept introduction phase. The units of mass and energy were chosen to establish the square of speed of light as the constant of proportionality that relates mass and energy in the equation. As an application of the mass-energy relation, electron-positron annihilation was introduced.

4.2.2 Exam test and results

After teaching the topic in a class a test was administered and 12 students from the class completed the test. The purpose was to see if students are able to recognize different conservation laws in the problem involving the process of pair creation in a nucleus. The rationale for using the pair creation example was that students already were aware of annihilation because of its discussion in the class and the other context was asked to assess their learning about mass-energy conversion. In the test, an interaction was presented where a gamma ray from a nucleus changed into an electron and a positron. Students were asked to a) write down at least one conservation law in the process b) state how to find the energy of gamma rays if masses of electron and positron is known c) describe where the energy goes if the energy of gamma ray is more than the minimum value needed for pair production.

The test was examined and returned to the students. I collected key ideas expressed by the students in their answer sheets. Some themes which emerged out from the results of the test are summarized as follows.

1. Knowledge of Einstein's mass-energy equation: Most of the students who participated in this study (9 out of 12) could immediately identify mass as a form of energy. They explicitly used mass of the electron and positron to find the energy of gamma rays, and they mentioned that the energy of the gamma goes into energy in the form of mass of the electron and positron.
2. Conservation process: The majority of the students (8 out of 12) considered charge conservation as the main conservation principle involved in the pair production process. Whereas energy conservation was considered by fewer students (5 out of 12)[1] students. The results in theme 1 indicate that most of the students were aware of the energy conservation in the pair production process. They might not have written down the energy conservation principle because

[1] In some of the categories the number of students adds greater than 12 because some students expressed multiple answers.

they were asked to write at least one conservation principle and they picked only charge conservation.

3. Additional energy of gamma ray: In response to the third question students expressed different views about conversion of surplus energy of the gamma ray. Some students (4 out of 12) considered that energy goes to some sort of mass without further explaining what that form means. Few students (2 of 12) reported that additional energy from the gamma ray converts to kinetic energy of the electron and positron whereas another group of students (3 of 12) expressed their view that additional energy goes to heat or light. Students' everyday experience or physics experiments might have influenced them regarding the conversion of surplus energy into heat or light because they often encounter such situations where extra energy is converted to heat or light. As yet another example two students stated that the additional energy goes to increase nuclear energy and one more student said that as long as the energy remaining converts to mass there is no left over of any energy. This particular student might have thought that all energy should be converted to mass. A student who held more scientific reasoning wrote "… production of some other particle is possible if gamma rays are of higher energy…but I am not sure…" It is apparent that this student relates energy with mass and realizes that mass is a characteristic of a particle.

4. Identification of the problem: Two students wrote without being asked "…the pair production is the reverse of matter-antimatter annihilation…" and "…annihilation is the process of two opposite masses interacting and becoming a gamma ray whereas pair production is the formation of an electron and positron from gamma ray…" this suggests that those students were aware that they were applying their learning of the mass-energy relation in a context different from learning context.

The mass-energy relation and electron-positron annihilation are considered abstract ideas. The exploration of student understanding of the mass-energy relation indicated that students can understand those concepts easily if they learn with active engagement. The result that they identified mass-energy equivalence and they applied the concept successfully in pair creation process is the concrete example of their learning. Students are however found to be influenced by their prior knowledge e.g. conversion of energy into heat or light. This is an example of inappropriate transfer of learning from prior experiences. More useful information could be obtained if further interviews were done which was not logistically possible at the time.

4.3 Experts' Interview on Teaching Positron Emission Tomography

A qualitative research method was used to investigate pedagogical experts' views on instructional strategies of the physics of positron emission tomography (PET). Through this effort, I aimed to understand teacher's ideas and beliefs about introductory level physics students' understanding of some of the key aspects of physics of PET. The output of this stage of study was to design the research protocol that would be used in the next phase of the study which is discussed in Chapters 5 and 6.

Specifically the following research questions were the focus for this stage of the study.

1. What are the difficulties in teaching and learning physics of PET in introductory level physics?
2. What are the appropriate teaching strategies to help students apply their physics knowledge in application to PET?

4.3.1 Method

Participants

Two people (one male and one female) from the physics education research group at Kansas State University participated in this study. Both the participants had teaching experience at introductory level physics. The first participant (M) had teaching experience of more than 9 years at college level and the second participant (F) had college level teaching experience of more than 4 years in different cultures. They were chosen because they were willing to participate and were from different cultural backgrounds.

Materials and Process

In depth semi-structured clinical interviews were conducted. The interview protocol included 11 questions (Appendix B). The questions were carefully worded and included different types of question (Minichiello et al., 1995) in order to fully understand participants' views from different perspectives. The same questions were asked to both the participants with the exact same sequencing and identical wording. During the interview, I focused on understanding their views about physics courses and medical diagnosis processes. In terms of student learning the interviews mainly focused on positron emission tomography related to physics concepts. I also tried to investigate their views about teaching strategies regarding these physics concepts in context of medical imaging process.

Table 4.4: An Example of Data Coding and Tabulation Scheme

CATEGORY	KEY WORDS FROM CODES	TOTAL	LINES
Knowledge (PK)	Conservation laws	3	035, 047,051
	Comes in, goes out, and interacts	4	036,044, 045,047
	Cross- section	3	061,066
	Emission and detection	1	067
	Don’t know the PET concept well before	3	019, 056,122
	System and interaction	1	140
Course (CC)	Knew the pre-med course before	1	091
	Unaware about lab class in the course	1	093
	Limited responsibilities as instructor	5	092,095,132,235,237
	Taught only second semester	1	210
	Know the similar courses elsewhere	1	097
Pedagogy (PC)	Focus more on concepts than applications	1	098
	Concrete concepts results less benefit	1	100
	Exam oriented learning	2	107,248
	Application parts essential	2	112,114
	Connection among different concepts	3	123,126,129

The interviews were audio recorded and field notes were taken during and after the interviews. The interviews were then transcribed. The analysis of the interview began with reading the transcripts several times. After getting the overall idea from the transcript, the important segments were underlined and various categories were labeled and defined. Participants' ideas were tabulated under different categories like an example shown in Table 4.4.

4.3.2 Results of the Study

The pedagogical experts expressed their understanding of PET based on what they currently know. They considered the conservation laws (coded 3, 13 times)[2] as the major underlying principles of positron emission tomography (PET). They believe that emission and detection are the key mechanisms of the process (coded 6, 7 times). They had heard of PET somehow in college level but they had difficulty in recalling what they knew. They expressed their views that students at introductory level college do not have knowledge about the application of physics in context of medical technology such as PET.

Both participants expressed ideas about pre-med physics courses based on the introductory level physics course they are familiar with. They thought that the instruction is similar in all introductory physics courses (coded 11, 3 times). They are not satisfied with the current instruction about physics where less emphasis is given in application parts in physics concepts. Informants showed concern that medical applications (including PET) are not emphasized in courses or in teaching (coded 8, 3 times) and believe the urgent need to introduce applications (coded 4, 3 times). They are not willing to change it because of their low authority in course decision making (coded 2, 5 times). Both informants stated that students are not able to apply physics learning because of exam-oriented instruction (coded 2, 2 times) and the traditional instruction where emphasis is on abstract concepts and not on applications (coded2, 2 times). The above similar beliefs may be because both are from the same discipline (physics), and similar work (do research in physics education and teach recitation classes).

There are some variations in their views. One of the participants believed that pedagogy is more responsible for students' failure on understanding medical (PET) underlying physics

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[2] The first and second numbers in the parenthesis are the total number of times the responses are coded in the first and second transcript respectively. This applies for all parentheses having two numbers.

concepts (coded 11 times)[3]. He thinks that teachers' special attention is important. For him, course structures are good (coded 7 times), but the sequence should be changed. The other participant is more skeptical about course structure. For her, both the course structure (coded 8 times) and instructional methods (coded 9 times) are unproductive. One participant highlights the importance of connection between the concepts and application (coded 11times) whereas for the other participant real world and medical-related problem solving are more important (coded 4 times). The variation in their thoughts can be because of their difference in experience (one is a doctoral research fellow, the other is a graduate student), schooling (one got undergraduate degree from the US, the other from China), culture (one is from the US, and the other is originally from China), and gender (one is male, and the other is female).

4.4 Coincidence Detection and Image Construction Activity Development

The studies described above indicate that students at the introductory level do not have much opportunity to learn physics of PET from their introductory level physics classes. It led me to think that students' clinical interviews about their understanding of PET and application of physics in PET do not give valuable information. I decided to design some teaching activities that resemble to some portions of the working of PET and then use those activities in teaching interview sessions. The major investigation within this part of the research was to explore the student learning process of physics within the context of image construction process of PET rather than their current knowledge about PET.

In this section, I describe the activities and the pilot test of some of the activities. A set of activity was pilot tested with an undergraduate student and then in a class. The goal of these efforts was to get feedback from such tests and to draft the teaching activities. The drafted materials accompanied by the activities were used in teaching interview sessions, which are described in Chapters 5 and 6.

4.4.1 Activity Introduction

I planned to use analogies to help the students understand the abstract and complicated ideas of PET. As discussed in Chapter 2 the most important part of image construction of PET

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[3] The number corresponds to the total number of times the response is coded in the transcript of corresponding informant. This applies for all cases if there is only one number in the parentheses.

involves the determination of lines through the body upon which the events producing the gamma rays must have occurred. Those lines are known as line of response (LOR) and are used to locate the region of activity inside the body. On the other hand time of flight PET (TOFPET) uses the speed of light, and the time difference between the detection of the two gamma rays to determine the distance from the detector to where the events were located. The first activity, which uses collision carts, is called the cart activity throughout this dissertation. This activity is related to the idea of TOF. The second one is called light activity, which involves a series of small light emitting diodes (LEDs) inside a cylindrical enclosure. This activity provides the analogy of drawing LOR.

The Cart Activity

The cart activity concentrates on the concept of coincident events. For locating annihilation event in PET scanner a set of detectors are used to detect two gamma rays. The gamma rays arrive at their respective detectors at a fraction of a second apart. The difference in the time between those two detections is used to determine the location of the event that created both gamma rays. To help students understand this concept an experiment was set up. The activity uses two PASCO collision carts with magnets in them. The carts are kept on a track and brought close to each other. When they are released, the magnets on them repel each other and the carts move away from each other.

Figure 4.1: Cart Activity

A large board is placed as a barrier in front of the track such that a student sitting behind the barrier can see the carts only when they reach the end of the track but not the location at which carts were released (Figure 4.1). Another student sitting on the other side of this board releases the carts. The first student who sits behind the barrier is asked to determine the approximate location of the release. In an ideal condition when the speed of carts are equal and if the cart on the left strikes the end much sooner than the one of the right, students would qualitatively conclude that the release (event) occur on the left side of the center of the board. If they see that both carts strike at about the same time, they would assume that event occurred approximately in the middle. On the other hand, for the quantitative determination of the location of the carts release, the students are supposed to measure the time difference between the two carts striking the end of the track and know the speeds of the carts. Use of a simple kinematics equation leads them to the numerical result.

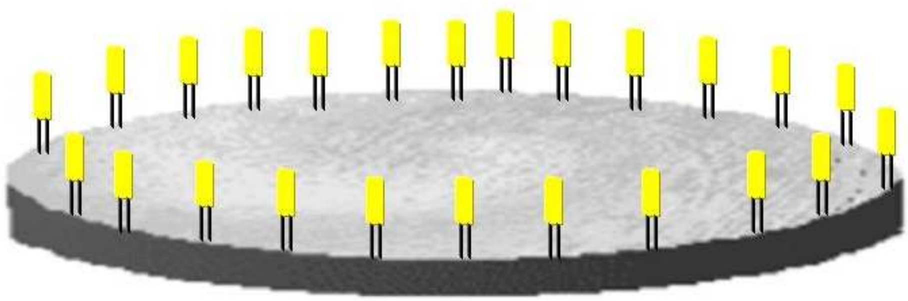
The Light Activity

Large number of detectors is configured in a ring in a PET scanner. The image-processing unit identifies the pair of detectors activated by gamma rays and this information is used to construct image. The light activity is an analogy of this portion of PET. In this activity a series of explosions is simulated. It uses a translucent cylindrical enclosure as shown in Figure 4.2. The lights pulses on the wall of the cylinder are visible but not the source that produces the light pulses.

Figure 4.2: Light Activity

The fundamental differences between the cart activity and the light activity are that the cart activity is one-dimensional situation involving just one event whereas the light activity deals with events in two dimensions with several different events and the cart activity represents TOF whereas the light activity represents LOR. A pair of light analogous to the two gamma photons represents each event in the light activity. By recording the location of several events and establishing the line of response for each of them, the students are to work backwards and try to determine where inside this cylinder the events, which produced the light pulses, would be.

Figure 4.3: Configuration of LEDs Inside the Cylindrical Enclosure



Inside of the cylinder is an array of light emitting diodes (LEDs) of identical size and brightness. The evenly spaced 24 yellow LEDs inside the circumference of the enclosure as shown in Figure 4.3 are used to make 12 pairs.

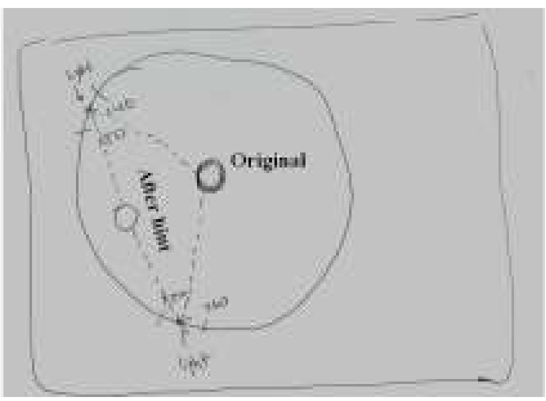
An electric circuit is designed so that when a switch activates only one pair of LEDs turn on. However, students are not told about the circuitry mechanism. They can only see a pair of LEDs turned on at a time. The students are told that the set up is designed to simulate the results of an explosion. The different pairs of LEDs are turned on in such a way that when students draw the lines connecting the respective pairs, the lines intersect in a region. This region simulates the area where many explosion events take place. Students are supposed to use statistical reasoning to come up with the idea that the region of more intersection of lines gives the region where majority of the events have probably occurred.

4.4.2 Pilot Test with a Student

The light activity was pilot tested in Spring 2006 with a senior undergraduate student who had enrolled in upper division physics courses such as mechanics, thermal physics and electromagnetic theory. A worksheet (Appendix F) was given to the student while engaged with the activity. She worked alone with minimal guidance and hints. I had told her that she could ask me for the clarification of questions in the activity if necessary. After she completed the activity, I asked her to reflect on it and about her difficulties in doing the experiment. I noted down various points from the student's reflection about the activity and her responses to the questions.

1. Influence of prior physics experiment: In response to a question regarding the location of source producing light the student considered that the source is at the center of the circle. To draw the paths of lights coming out from the circle she started out from the center of the circle, which I labeled as ‘original’ in Figure 4.4. Upon being asked the reason behind her answer she mentioned that there should be a crystal at the center of the circle and when the switch is rotated the crystal rotates and lights are seen at different location. Further probing revealed that her reasoning was influenced by Bragg’s law (Bragg, 1912) experiment that she did in her prior physics class where the set up was similar to this one and x-ray diffracting crystal was at the center of the cylindrical enclosure. This kind of inappropriate influence of prior activities is an example of negative transfer that I discussed in Chapter Two (Perkins & Salomon, 1992).

Figure 4.4: The Student’s Sketch of Event Location

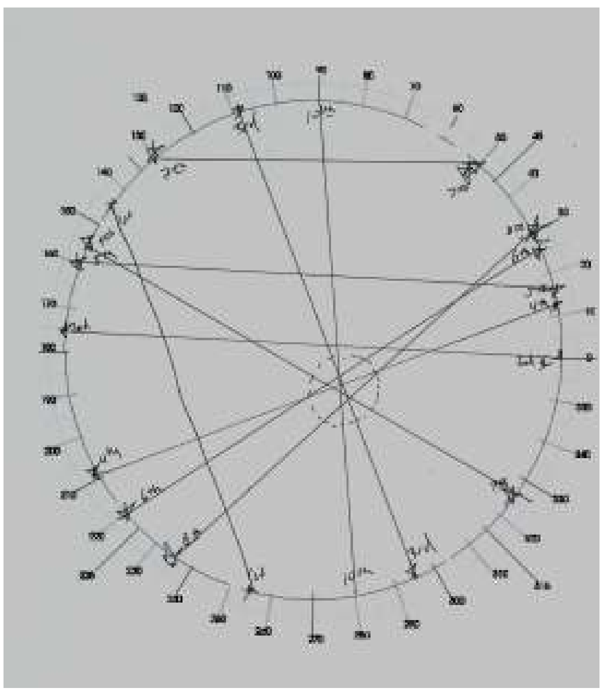


2. Momentum conservation: The student was told that the lights are the results of explosion of an object. The major physics principle involved in the process is momentum conservation but the students could not apply the idea of momentum conservation herself while doing the activity. Upon being told that momentum conservation should hold in the process, she was able to draw the lines to represent paths of explosion bits. She drew the straight-line path connecting the lights, which I label as ‘after hint’ in Figure 4.4.
3. Difficulty in drawing a pattern after observing lights: She was asked to see the different pairs of lights and draw the pattern. She found the term “pattern” rather difficult in the context of the activity. The meaning of pattern to her was regular trend or regular shift of the light positions. This did not happen in this experiment and she

had trouble figuring out the pattern. After she realized drawing lines for each event and saw the lines crossing in her worksheet as shown in Figure 4.5, she was able to make sense of the pattern.

4. Statistical reasoning: She completed drawing all possible lines after observing the lights. She drew a small circle in the region of lines of intersection as shown in Figure 4.5 to pinpoint the region where the majority of the events producing lights were situated. She said that even though she was not certain about the location of individual events based on one line, she could determine that the region of intersection of many lines is where many events should be crowded. She further explained that the greater the lines or pairs of lights the more precisely the region could be determined.

Figure 4.5: The Student's Drawing of Multiple Events



4.4.3 Pilot Test in a Laboratory Class

Both the light and cart activity were introduced in the Contemporary Physics laboratory class in Spring 2006. Six students who enrolled in the laboratory section of the class were divided into two groups. The cart activity and the light activity were tested as parts in a laboratory that involved various experiments related to determination of hidden events. A work sheet in the laboratory manual format was provided (Appendix G). A laboratory instructor taught the class in traditional laboratory format where instructor introduces the laboratory followed by students working in groups.

Students were supposed to locate hidden events in the cart and the light activity as described in Section 4.4.1. I observed the class and asked students probing questions and made a few notes during the class. Later, I requested the laboratory instructor to provide me their laboratory reports. I summarize my analysis of the study the cart activity and light activity subsection as follows.

Cart Activity

Students were comfortable with the cart activity in determining the hidden location of the carts release. They were provided distance time equation in the worksheet and asked to measure speed of each carts. A barrier was then placed, and one student was asked to release the carts while others were asked to measure time difference to figure out the location of carts release. Finally they were asked to compare their calculated and actual values and discuss the sources of error. Students performed all the mathematical parts successfully. They worked together in groups, and the mathematical parts of the answers were identical within individual groups. Both the groups of students needed help in deriving equation to find distance traveled by each cart from the one that involves difference in distance traveled.

In response to the question about uncertainty in the determination, they had different opinions. The most popular response (frequency 4) was the consideration of friction in the cart as the major reason for not having accurate results. Another considered reason was that the velocity of the cart was not constant throughout the motion (frequency 2). Yet another idea prevalent among students was the human error in timing due to problem in hand and eye coordination (2).

Light Activity

I found some variation between two groups while performing the light activity. The first group immediately started out from the center of the circle to connect two lights whereas the other group connected each pair of lights with straight lines. Up to this point none of the group recognized that principle of momentum conservation should be used. The reasoning of the first group was that center is the easiest point to start with when circle is involved, whereas the reasoning of the second group was that the straight line is preferred to join the two dots. Both the groups of students seem to rely on their prior experiences in this part. It can be argued that if students cannot do scientific reasoning they rely on their available cognitive resources (diSessa, 1993; Minstrell, 1982; Minstrell, 1992). However, each group applied a different aspect of geometry as their reasoning resources.

The students were then told that momentum should be conserved in the process. The first group of students who started out from the center immediately changed their drawing to connect the dots by straight lines. The second group of students who connected dots by straight lines already realized that their earlier reasoning was not scientific in this context. The first group of students reached the consensus that light does not have mass so its momentum should be its speed whereas the second group of students did not even know what the momentum of light means.

Both the groups identified region of many events but they were in different locations. The first group was more focused on the entire quarter of the circle whereas the second group pinpointed the region of the intersection of the lines. However, both groups used the similar reasoning concerning intersection of lines to find the region. It could be possible that for the first group region means wider area so they picked entire quadrant. The first group was focused on each individual line to find event location along the lines. After getting scaffolding (I asked them which light came up first) they came up with the idea that individual lines cannot provide information about the location of events. The second group did not need any scaffolding to come up with this idea.

4.4.4 Summary of the Pilot Studies

While doing their task in the cart activity students completed the structured mathematical steps without realizing any connection to the physics laws. The pilot test of cart activity led me to think that instead of providing the equation directly to students it is better to see what physics or mathematical reasoning they bring to interact with the activity. Rather than giving students a quantitative task, I opted to begin with a qualitative task and then ask them to perform quantitative task.

The pilot studies of light activity informed me that students have difficulty in identifying and using the idea of momentum conservation themselves in this experiment unless they are told. Most of the students were able to predict the region of events in the light activity after completing drawing. This encouraged me to use the drawing activity to help student understand

PET imaging process by the idea of line of responses (LORs) and their intersection. The results of the pilot tests feed into the development of teaching interview protocol which is used in teaching interviews that are described in Chapters 5 and 6.

4.5 Chapter Summary

In this chapter, I mainly discussed the development of the instructional activities that describe the physics of PET. An exploration on students' understanding of radioactivity was done, and an instructional unit was designed. The instructional activity on mass-energy relation and annihilation was created and tested in a class. Likewise, hands-on activities that cover aspects of PET image construction process were developed and pilot tested.

Furthermore, I also conducted a survey and interviewed the physics education researchers at Kansas State University. The purpose was to understand their perceptions regarding college students' ideas in radioactivity as well as their views on physics teaching with medical application. A qualitative research methodology was adapted to conduct the study and to analyze the data.

Based on the analysis of data from the surveys, interviews and tests various results were noted down. The education researchers perceived that the physics teaching should emphasis the physics application in many areas such as medical technology whereas the current physics courses do not emphasis the medical application. The researchers' perceived that the students do not know about PET and do not have good understanding about the positron. Students' survey result indicated the similar result regarding their knowledge about the positron. Another result of the study shows that the students were able to learn mass-energy relation and electron-positron annihilation through interactive activities.

This phase of the study led to the development of the teaching interview protocol, which was used in the next phase presented in Chapter 5. I learned, through the effort of this phase of the study that it is logical to investigate how students learn physics process involved in PET. Rather than investigating students' physics ideas related to PET individually, it was found logical to investigate how they understand those ideas while learning PET. I decided to discuss a range of physics ideas related to PET while the students interact with the cart activity and the light activity. I aimed to investigate how they transfer their prior physics learning in understanding the physics ideas in the learning context of PET.

CHAPTER 5 - Investigating the Role of Physical Models in Transferring Physics Learning

5.1 Introduction

The exploration of students' thinking and assumptions when they engage actively with physics learning activities was the main focus of this phase of the research. I was interested in seeing themes, patterns or trends in students' reasoning rather than their immediate responses. The final output of the effort was to describe the ways students learn and apply their physics learning. It was considered essential to conduct qualitative teaching interview not only to unpack their thinking and knowledge patterns but also to investigate the changes in their ways of thinking.

In this chapter, I describe the individual teaching interviews of introductory level physics students. The goal of the teaching interview was to investigate student learning and transfer of learning of physics using the physical models. The teaching interview instrument that was administered to the 16 students from Kansas State University is presented. The analysis of the interview data is likewise described in the chapter. The exhaustive description on the final results of the study concludes the chapter.

5.2 Research Questions

The main goal of this phase of the research was to answer the following research questions.

1. What cognitive resources do introductory college students bring to bear when interacting with physical models?
2. Does sequencing of different physical models affect activation of these resources?
3. How do students transfer their physics learning from physical models to understand PET?

5.3 Research Methodology

This phase of the research adopted phenomenography (Marton, 1986) as a methodology in both the data collection and data analysis phase. The qualitative data were collected by series of teaching interview (Engelhardt et al., 2003). The design of the teaching interview adapt the learning cycle of Karplus (1977), as its pedagogical framework and thus is consistent with the perspectives of constructivism of Piaget (1964) and Vygotsky (1978) as well as the contemporary perspectives of transfer of learning (Bransford & Schwartz, 1999; Greeno, Moore, et al., 1993; Lobato, 1996).

5.4 Data Collection

5.4.1 Invitation of Participants and Getting Their Consent

The students were invited by sending e-mail to participate in the study at a time convenient to them. They were offered $10 for each hour after they completed both the sessions. No attempt was made to select a representative sample of students from the class. After discussing the purpose of the research they were assured that their performance in the interview would not affect their course grade. Moreover, I explained that for the purpose of the teaching interview there was no right or wrong answer, and I was interested in their reasoning rather than the correctness of the answer. I also followed the IRB (Institutional Review Board) Guidelines for human subjects. They were assured about the confidentiality of data and their right to discontinue their participation at any time. Even though the video was not recording the face, they were requested to grant their permission to video and audio record the interview. Finally after getting their consent of participation in the study, they were asked to sign the IRB consent form (Appendix H).

5.4.2 Research Setting

The study was conducted at the main campus of Kansas State University in Spring 2006. Sixteen students, eight females and eight males, participated in this study. The students were enrolled in an introductory level algebra-based physics course (General Physics 1 and 2); nine of them were pre-med students and the rest of the students were chemistry and biology majors. The study was done during the second half of spring 2006 since kinematics, which was the prerequisite to participate in this study, was covered in their physics class by then.

The teaching interview sessions were held in a specially prepared interview room within the fourth floor of Cardwell Hall at KSU. The interview room provides a quite, non- threatening environment and is well equipped with audio-video recording equipment. To create a relaxed atmosphere and form rapport with the students, I commenced each session by discussing their area of interests, major and high school studies.

5.4.3 Teaching Interview Protocol

The teaching interview protocol consisted of modified questions from the pilot tests described in Chapter 4. In the pilot test, questions were put in a laboratory format and the teacher did not ask probing question. Only one question was introduced at a time to the students during the teaching interview and then follow-up questions were asked. Wherever necessary, successive prompts and hints were provided to the students to help them respond to the question. The teaching interview protocol was further modified after getting feedback from the colleagues and advisors who completed it in a setting similar to a real teaching interview.

The teaching experiment sequence consisted of a fixed protocol, but depending upon the students' responses, several scaffolding activities were introduced. The protocol consisted of two sessions each about one hour long. The spacing between the two sessions was 5 to 7 days depending upon students' availability for the second session. Students participated individually in the sessions that resembled mock instructional setting where my role was as a teacher-interviewer to provide appropriate scaffolding to help students construct knowledge. An observer, upon request, observed some of the sessions and gave suggestions about the weakness and strength of the interview process. I varied the depth of probing of individual questions in order to further investigate issues raised, but the major questions asked were the same for all sessions. Students were engaged in a conversational style of questioning rather than rigidly asking each question. This style was adopted to encourage student to articulate their physics knowledge and everyday experience in their own words.

The goal of the teaching interview was not only to find the effective teaching methods, but also to investigate the variations in the student learning progression and the factors that influence these progressions. As Komorek & Duit (2004) pointed out, teaching interviews can be helpful in structuring and refining teaching materials. The goal of this effort was to plan learning experiences for students in helping them understand and apply the physics principles of PET.

5.4.4 The First Session of the Teaching Interview

The first session of the teaching interview used hands-on activities described in Chapter 4 (Section 4.4.1). These two hands-on activities will be referred as physical models in this and subsequent chapters. In addition to these two physical models, scaffolding activities were used wherever needed to challenge students' inappropriate reasoning.

Each set of activity started with a student exploration followed by questions. In that sense the initial part of the activities resemble the exploration phase of the learning cycle (Karplus, 1977) where students explore and test their conceptions using the activities with minimal teacher intervention. They were asked a series of questions (please refer Appendix I). Here I describe the several steps that students went over during the first session. First I discuss the various parts within cart activity labeled as C1, C2…etc.

Figure 5.1: Activities of First Session

Cart Activity   Light Activity   Light Scaffolding

Activity C1: Observe the Carts

The magnetic repelling carts were placed on a track and students were asked to explain their behavior when they are released. The carts were then placed on the table and again students were asked a similar question. They were asked to compare the speeds of the carts and the factors associated with the carts that alter their speeds. Whenever students themselves did not bring up the physics concepts involved they were asked if they see any physics laws or principle involved in the process. They were also asked the methods or equations in finding the speeds of the carts.

Activity C2: Qualitative Location of the Carts

A barrier was placed in front of the track so that students were able to see the end of the track but not the location where I released them. The students were told that the carts were brought together and released. They were asked to discuss the location where they started. At this point they were supposed to estimate the rough location based on their qualitative reasoning.

The typical student answer would be "…the left cart hit the end much sooner than the right cart so the carts must be released very close to the left side…" or "…both the carts appear at the ends approximately at the same time and assuming that they were traveling with the same speed they must have started near the center of the track…"

Activity C3: Quantitative Location of the Carts

At this stage of the activity, they were asked to discuss the ways to find the numerical value of the location of the hidden event. The carts were released several times with the barrier hiding the release to trigger their reasoning. As a scaffolding measure, they were cued by asking what they would measure in figuring out the location. They were also asked about the quantitative process to follow after doing such measurements to get the result. Students' were supposed to bring up some mathematical reasoning to approach this quantitative task. However, I did not expect all students to use one single approach to get the answer.

Activity C4: Discussion on the Sources of Error

They were asked to discuss the sources of error in the experiment of finding the numerical results of the experiment. The purpose of this question was to explore students' perception about the prominent factors or measurements related to the experiment rather than the way of getting accurate results.

Students' typically considered friction as the major source of error in response to this question. However, the more relevant source of the error is measurement of time and speed of cart in this activity.

In the first session of the teaching interview, students also did the light activity which requires that the students go through series of activities that I discuss below. Following the same procedure as in cart activity I label the activities within the light activity as L1, L2…etc.

Activity L1:Observe the Light Pattern

Students were provided the light activity set up and asked to rotate the switch to observe lights. They were requested to explain their observation after looking several pairs of lights.

Activity L2:Observe a Light Pair

A hint was provided that a pair of lights appear on the walls of the cylinder as a result of an explosion and another pair as a result of another and so on. They were then told to concentrate on only one pair of lights and then discuss how to find the location of the event that gave rise the light pairs.

Activity L3: Simulating Behavior with Balls

I used a 'scaffolding activity' shown in Figure 5.1 using metal balls on a circle to simulate the explosion to supplement the light activity. Students noted the angular readings of the pair of light on the cylindrical enclosure. The same reading was replicated in the circumference of the circle in the board. Students then discussed on how to put a big ball inside the circle so that its explosion bits move to the desired points.

Activity L4: Use of Mirror to See Both the Lights

To know students' reasoning about the factors they would consider in locating the event I used mirrors as another activity. Two mirrors were provided so that they could see both the lights together. Since both lights could be compared in brightness, size and time to appear together this activity allowed me to examine students' conceptual resources that are triggered in that context.

Activity L5: Use of Laser Pointers

Two laser pointers were used in some of the interviews to challenge students reasoning when they related location with intensity. Students were asked to tell the relevant measurements in locating light sources at a distance when nothing is known about the light source. This was particularly used when students were immediately considering that "all sources are of equal brightness" without being told.

Activity L6: Drawing the Several Explosions

Students observe several pairs of lights and record the positions of light on a circular graph paper. Their job is to note any pattern or trend in the graph. The intersection of lines is supposed to trigger their statistical idea that the region of intersection of lines might be the possible area where the many events are grouped.

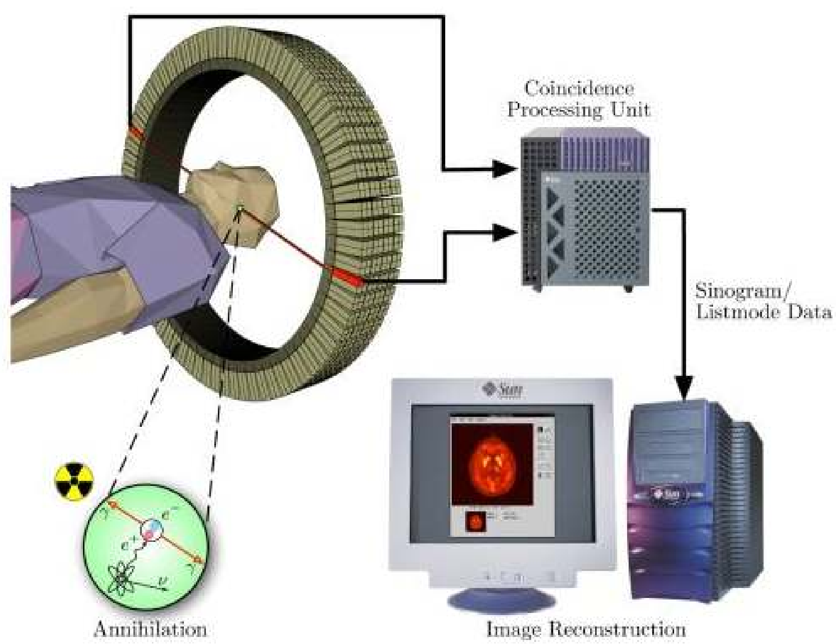
After the completion of the activities, they were asked to compare and contrast the cart activity and the light activity. They were also asked which of the activities helped them to learn related physics ideas more. I requested them to give their opinions about modifications of the activity.

5.4.5 The Second Session of the Teaching Interview

The second session began with the discussion of general ideas of positron emission tomography (PET). Students were then provided with the pictures and diagrams related to the physics problems of PET technique. Some physics terms relevant to the first session and subsequent activities of the second session were discussed. This portion of the session was therefore similar to the concept introduction phase of the learning cycle. The rest of the activities of this session involved the application of their prior learning and therefore resembled the concept application phase of the learning cycle.

The production of gamma rays in the annihilation process is considered as the key mechanism involved in the image construction process in PET. Students were engaged in the discussion about the gamma ray production and their travel. After that students had to perform a series of activities to locate the exact position of electron-positron annihilation in the brain. They were finally asked to do activities to find the region of the tumor using PET technique. Once again I follow the same procedure of labeling different activities in second session as in the first session. I am now labeling the activities in the second session as P1, P2…etc.

Figure 5.2: Annihilation Locating Activity (source wikipedia)



Activity P1: Determination of Number and Direction of Gamma Rays

Students were provided the background of PET and told that a tracer is administered to the body of a subject. The tracer gives off tiny positively charged particles called positrons through beta activity. The emitted positron annihilate with electron to give gamma rays. They were also given information about masses and charge of an electron and positron. A hint was given that momentum of the electron-positron system just before they annihilate is zero. After providing this much information students were asked to draw and describe the number of gamma rays produced in the process.

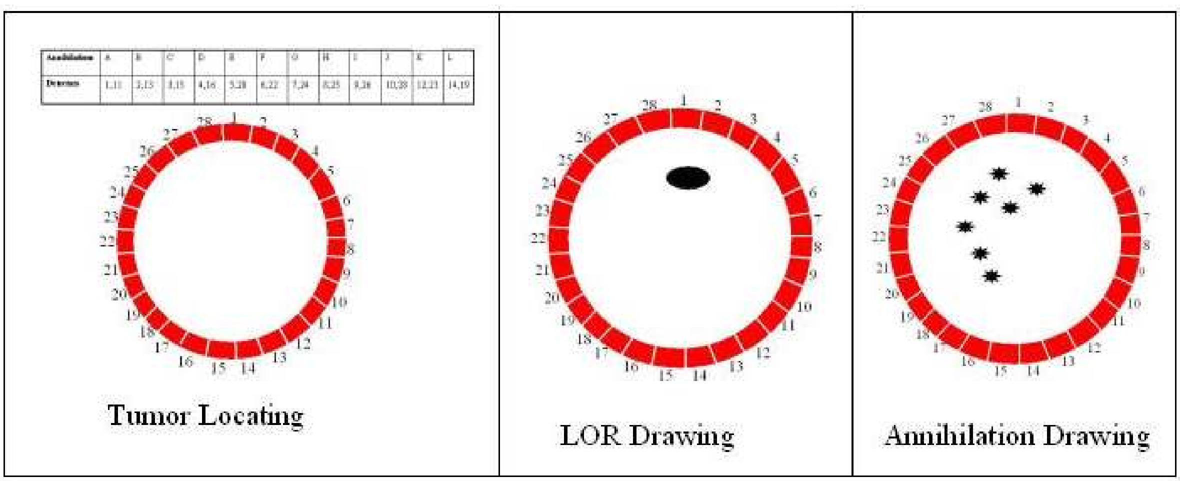
Activity P2: Determination of an Annihilation Location

A picture was provided (Figure 5.2) and they were asked to describe the process of annihilation event location in brain.

Activity P3: Locating Tumor

A series of drawing activities were introduced one after another. The first one was a tumor locating activity where students were given a detector configuration and a set of annihilation data (the first one in Figure 5.3) to ascertain the tumor structure.

Figure 5.3: Drawing Activities Used in Second Session



Activity P4: Drawing LOR

A tumor was located inside a detector ring (second of Figure 5.3). The students' task was to draw a possible pattern of gamma rays.

Activity P5: Drawing Gamma Rays from Annihilation

Stars within the detector ring represented a set of many annihilation events (third of Figure 5.3). Students worked to draw the pattern of gamma ray detection around the ring.

At the end of the session, students were asked a few questions to reflect on what they had learned in the process. The purpose was to cross-examine my interpretation about their learning. While reflecting about the process, they also described their comments and suggestions regarding the activities. This has been considered as important input while finalizing the teaching materials using the teaching activity. The students were thanked for their participation and provided with the offer of follow-up information on their interview.

5.5 Data Analysis

The data analysis was accompanied by an inter-rater reliability test. Various segments of the interview transcript were tabulated. Different categories were defined and various codes were assigned within each category. Five physics education researchers at Kansas State University were provided with the tabulated segments of the data along with the category names, definitions and codes (an example is presented in Appendix K). The researchers extracted the themes, labeled the categories and coded them independently. The codes within each category were tabulated (Appendix L). An inter-rater reliability of more than 67% was established among the five researchers.

The seven-step procedure consistent with Colaizzi's phenomenological analysis technique was used in analysing the data. Table 5.1 maps the steps that I followed with Colaizzi's seven steps.

Table 5.1: Adaptation of Research Steps

Colaizzi's Steps	Steps followed in this research
Review of the collected data and get a sense of whole	The video was watched in a single sitting and the inherent meanings were drawn. The interviews were transcribed that contained the questions, hints and prompts.
Extraction of significant statements and phrases pertaining to the phenomena	The important segment, statements and phrases were underlined in the transcript. The highlighting of the significant statements was based on the questions, hints and cues that were provided to the students.
Formulation of the meaning from the significant statements in the context of the subject's own terms	An association diagram was made using the significant statements. The diagram used the two-level framework of transfer of association of 'read out information' and 'the learner's prior knowledge and experiences. The controlling factor was judged based on the provided activities as well as the hints and cues.
Organization of the meanings in a cluster of themes and theme categories	The association diagram was examined with various parts of the interview transcript and similar associations were put together and a common category was applied to them. Various segments of the transcripts were sent to five different researchers to categorize the segments independently.
Integration of results into a rich and detailed analytic description called as an exhaustive description	Themes were then generated by comparing the categories of associations at different parts of the transcript of a student to present the detail description of the students' reasoning
Formulation of essential structure of the phenomena	Various different results having same underlying reasoning across different students' interviews were combined to structure a meaning
Validation of the findings by taking back to the subjects	Students were asked at the beginning of second session to verify the meaning drawn from their responses in first session

5.6 Results and Discussion

The results will be presented in terms of the variations of association made by students' when they interacted with different activities and different sequences. An example of the association made by students within different categories is presented in appendix O. Major themes resulting from the independent categorization and coding of the interview data are tabulated in Table 5.1. Different results are presented in three main subsections.

Table 5.2: Tabulated Codes of Different Categories

S	CC	CL	IT	CI	MM	DG	EG	TT	OM
1	Y	Y	S	Y	Y	N	Y	SS	×
2	Y	Y	I	N	Y	Y	Y	SS	M
3	Y	Y	I	N	Y	N	Y	ST	×
4	Y	N	I	Y	×	Y	Y	NS	×
5	Y	Y	I	N	×	×	Y	SS	M
6	Y	Y	T	×	×	×	N	ST	M
7	Y	Y	I	N	×	×	N	SS	M
8	Y	Y	S	N	×	Y	Y		O
9	Y	Y	T	×	Y	Y	Y		M
10	N	N	I	N	Y	Y	Y		M
11	Y	Y	I	Y	×	×	×		O
12	Y	Y	T	×	×	Y	N		O
13	Y	Y	T	×	×	Y	Y		M
14	Y	N	T	×	×	Y	Y		M
15	Y	Y	T	×	×	Y	Y		O
16	N	N	T	×	×	×	×		M

The Acronyms used as the codes in the Table 5.2 have the following meanings. CC-Center to the Circle, CL- Center to the Line, IT-Intensity, Time, Size, CI-Cart Influence in Light, MM-Mechanical Model in Light, DG-Cart Influence in the Direction of Gamma rays, EG-Even Number of Gamma rays, TT-Types of Transfer, ST-Spontaneous Transfer, SS- Semi-

Spontaneous Transfer NS- Non-Spontaneous Transfer, NT- No Transfer, OM-Optical vs. Mechanical, Y-Yes, N-No, ×- N/A

5.6.1 Students' Reasoning

Here I describe various conceptual resources that the students used while interacting with the different activities.

Central Tendency

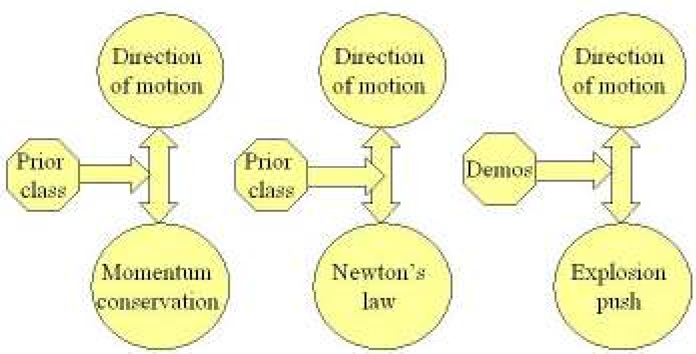
While engaged with the light activity, most of the participant students (88%) used the idea that the light-emitting source is at the center of the circle. When asked to explain their reasoning, most students appeared to have arrived at this conclusion based on their intuition. They stated that they automatically thought whenever there are two lights on the circumference of the circle their common origin must be at the center of the circle. Here is a typical statement made by one student:

> "I am so used to think that if you are gonna have two points at the end on the circle then obviously their start point is the center…."

To prompt them, I asked questions like "based on what you see in the activity would you believe that the event must occur at the center". Then the students changed their answers immediately and said that it could be anywhere inside the circle. Once they were reminded that the lights were the result of an explosion, nine students (63%) drew the conclusion that the explosion bits must move opposite so that the event should have taken place along the line joining the two dots. The remaining six students (37%) needed further scaffolding to come up with this idea. I used the 'light scaffolding activity' described in Section 5.4.4 to change their idea by cognitive dissonance method (Festinger, 1957). Students replicated the angular positions of the pair of lights from the cylinder to the replica board. Two balls were provided to simulate the explosion bits, and the students were challenged to start the balls from a position so that they, as explosion bits, get to the desired replicated points. This activity helped them to realize that the explosion bits move in opposite directions and they should start from a point along the line joining two light dots and not from the center of the circle.

To explain their idea of the direction of explosion bits, five out of 16 students (31%) explicitly mentioned that momentum should be conserved. Seven students (44%) brought up the idea of Newton's third law in the process, and the remaining four (25%) students did not use any physics law and said that if it is the explosion bits must move opposite. The variation in association made by different groups of students with the direction of bits travel is depicted in Figure 5.4. From our (experts') perspective, it is similar to associating direction of motion with the momentum conservation principle or Newton's laws of motion, but the discussion with the students revealed that they perceive these two laws differently. The lecture class influenced the students who made the first two kinds of association. Whereas, the students who made association of bits motion with explosion push argued that it is the rule that explosion bits move in opposite direction. For those students, their reasoning of "explosion pushes opposite" is kind of a facet of knowledge (Minstrell, 1992) because the students did not relate the phenomena with any of the physics laws, rather, they said that there is not any law but this is how explosion works. I speculate that they considered "explosion pushes opposite" as a self-explanatory piece of context dependent reality.

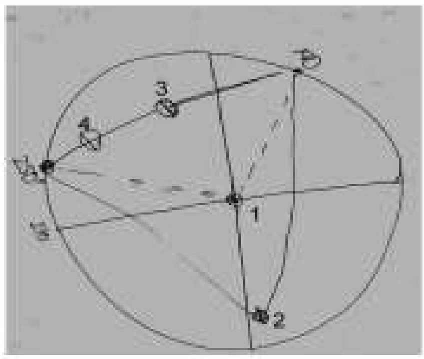
Figure 5.4: Variation in Association in Direction of Explosion Bit Motion



Students were found to hold the idea of central tendency in the line also. Once they realized that the particles move opposite to each other, a majority of the students (75%) said that the event should occur at the center of the line joining the two dots. Here is a representative student statement.

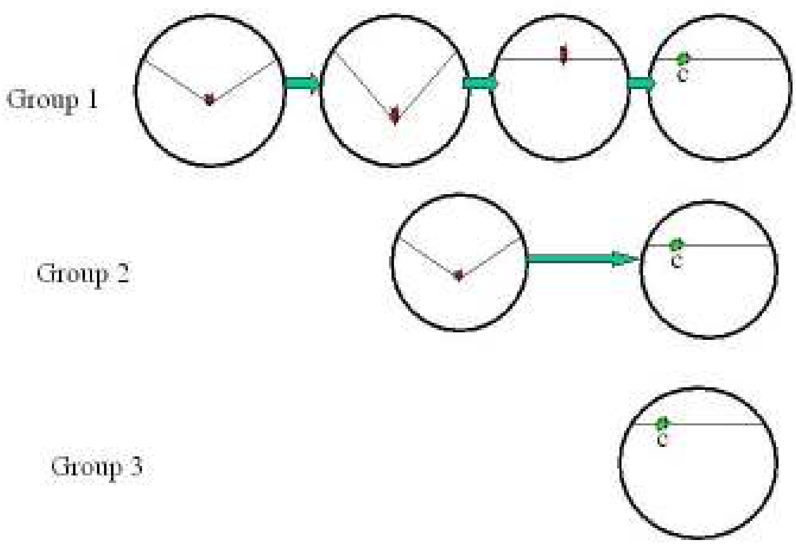
> "Kinda guess where the center is …I said the light source is at the center…I think the light source is at the middle of the line…for example in this line it (the event) should be somewhere at the middle of this line…"

Figure 5.5: A Student's Sketch Showing the Idea Progression



During the teaching interview this idea was challenged. Figure 5.5 shows a representative sketch of how students' ideas progressed with scaffolding. The stages are labeled as 1, 2, 3 and 4 in the sketch. Before receiving any hints the student thought that the event should be at the center (1) and later decided that it could be anywhere inside the circle (2). After the student was told that two fragments from an explosion produce light, he said that the event must be at the center of a line joining two lights (3). Finally, he realized that it could be anywhere along that line (4).

Figure 5.6: Variation in Progression



In Figure 5.6, I present the variation of the progression within different groups of students. I just explained the progression of majority of the students, which is represented by group 1 in Figure 5.6. There were just two students (13%) in group 2 who moved to the correct answer with single scaffolding whereas group 3 consisted of another two students who did not have central tendency and came up with the correct answer immediately without any help.

This study shows that the central tendency is very popular, but the good news is that it is very weak. The students did not hold it firmly and just asking for clarification changed their notion. I speculate that it comes mostly from prior everyday experiences or prior physics experiments. In Chapter 4, I gave an example of a student who held the similar type of central tendency but her base of argument was a prior laboratory experiment whereas this group of students revealed their intuition drawn from everyday experiences. It is reasonable to deduce that a symmetry argument might have led them to have the central tendency. Since this reasoning is not strong, it does not do too much harm like misconceptions but it is ubiquitous and may hinder student learning.

Students who associated motions of explosion bits with explosion push were influenced by the laboratory demonstration. It is encouraging that they came up with the correct idea with the aid of demonstration because they were able to associate their laboratory experience in a new situation. But, it is noticeable that those students are not willing to consider any physics laws that explain the process.

Event locating Factors

I was interested to know what kind of reasoning students use to locate the event that produces light. This study indicated that the students frequently used various pieces of knowledge (Clement et al., 1989; diSessa, 1993; Minstrell, 1992) during their reasoning process.

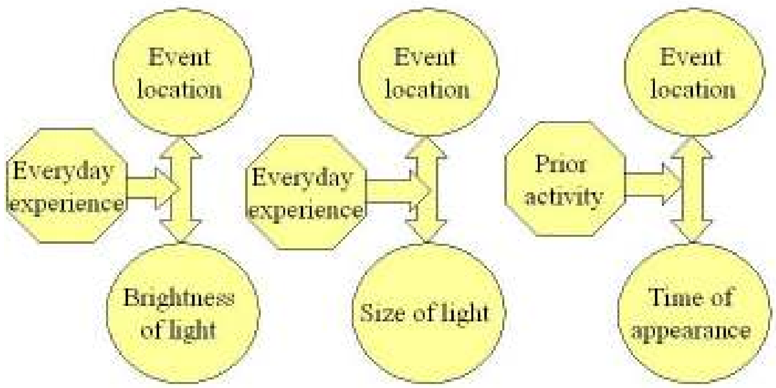
Once they decided that the event could be anywhere along the line of response, seven out of 16 students (44%) concluded that the event must be closer to the brighter LED. Those students who used the idea of "closer is brighter" in the context of light activity appear to be influenced by everyday experiences. They gave the example of street lamps and said that the closer one would be brighter than the one further away. The students, even before looking carefully at the lights on the cylinder, associated the location of the source with the intensity of light. This piece of knowledge works in many situations with light. In the teaching interview, 12 students concluded that the event must be in the middle of line of response. Seven of them used this type of reasoning to decide that the event must have occurred in the middle of the line of response.

For example,

> "I would have to look at the light again ….if the intensity of the light is same at both the sides…which I believe it is … I believe that the…it have to have happened at the middle."

This reasoning is good for some situations, but not appropriate here. The students were not sure about the light source because it was hidden, and they were even told that the light on the wall of the cylinder is the result of an explosion and both the explosion bits start from the same point together. In this situation, they were supposed to rely on the externally measurable parameters but it was not apparent from the study.

Figure 5.7: Association of Event Location with Factors



In a similar way, 2 of the 16 students applied the idea of "closer is bigger". The students looked for the size of the light on the wall of the cylinder before making a decision about the location of event. For example,

> "The diameter of the light was the same so I think it should be equidistance from the light source."

The final seven students (44%) who concluded that the event must be in the center of the line of response used a reasoning based on 'timing'. The idea of "closer is quicker" is illustrated by the following example,

"You have to see when the lights turned on … I thought they turned on at the exact same time."

It is interesting to note that most of the students who considered 'time' as an important factor to determine the location were engaged in the cart activity before the light activity. I will describe it in detail in the sequencing activities section.

I tried to challenge students' idea on intensity of light to locate the events. I started out with their example of street lamps that was their basis of reasoning. They were then asked about estimating location of stars. They used the idea of brightness and the size to compare the relative location in both cases. Finally, they were provided with a situation where I used two different laser sources and shoot the light together on the wall. They were cued that it is similar to a physicist's experiment. Three out of seven students of the intensity group stated that physicists first decide how fast the light travels and then measure the time to find how far it traveled. This kind of student reasoning can be explained on the basis of transfer model presented in Chapter 3 (section 3.6). Students activate different resource tools based on the external inputs. When they were provided the external inputs that fit with everyday examples, the activated 'source tool' is related to everyday life examples. In the above example, the source tool is 'brightness' to explain the everyday experiences like star and lamps. But, when the external input was 'physicist's experiment', they activated different resource such as 'speed', and 'time' because the students are aware of that kind of measurements in physics. The activation of resource depends on student motivation or beliefs and accessibility of tool. For example, if students strongly think that physics laws or rules explain the situation, then they search for an appropriate tool from the physics domain. If they are able to find a meaningful tool, then they use it while answering a question otherwise they do not give any answer. On the other hand, if they do not have a specific motivation, they could search the tool from either physics domain or everyday experience domain.

Momentum Conservation and Gamma rays in Annihilation

Two is not only the least but also the most probable number of gamma rays produced by a single event of electron-positron annihilation. Detection of two gamma rays is therefore the most common method in PET. It was decided to help students learn the idea that in the least two gamma rays should be produced to conserve momentum.

The discussion on electron-positron annihilation took place in the second session of the teaching interview in which 15 students participated. The students were asked to state the least number of gamma rays produced by one annihilation event. They were initially given an indirect hint that when electron and positron approach the momentum of the system is zero. But, none of them applied momentum conservation in the context of annihilation process unless they were directly told. The main reason could be their idea about gamma ray where momentum was irrelevant. One student considered gamma rays as the burst of energy and drew the picture of outward expanding spherical wave. Another student who was not sure about gamma rays stated as follows,

> “I don’t know how gamma rays work… I heard the term gamma ray when talking about chemical molecules and they are ranking like alpha, beta and gamma…but I don’t know what gamma ray would be…but I think it would be the strength of the signal that is produced”

As another example, a student expressed an even more complicated picture of gamma ray where they could not be able to apply the idea of momentum conservation.

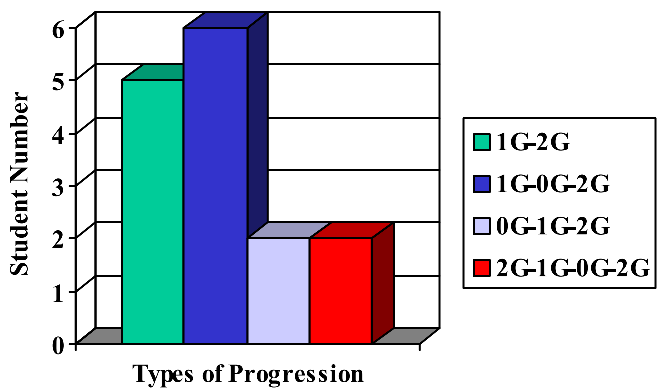
> “I have no idea like…I don’t know… it is something to do with like…waves in the air… just by one thing…I would just think they would go out in every direction…my picture is they would go every direction…not like one specific direction…I was thinking like one goes that side one go that side…(draw many lines from the annihilation spot)…they all go out… that’s what I think…”

Even those students who used the term electromagnetic radiation to explain gamma ray were unable to use the idea of momentum conservation thinking that the gamma rays lack of mass means that it has no momentum. It was apparent through the interview that the students related momentum to mechanical objects. I found four different variations in the students’ reasoning about the number of gamma rays produced in annihilation process. The variation is discussed on the basis of idea progression with the provided hints.

The statistics of types of progression is presented in Figure 5.8. The most popular progression was 1-0-2, which was found among the six students. The students started out with one as the least number of gamma ray produced in the process. After being told about the momentum conservation in the process they changed their idea and said that there should be none to get final momentum zero. Finally when they were reminded that mass of electron-positron goes in the form of gamma ray energy, they changed their answer and said that there should be two gamma rays so that both momentum and energy are conserved.

Five students held the second most popular progression of 1-2. They also started out with one as the least number of gamma ray, but after getting hint of momentum conservation they came up with the target idea. The third group of two students started out with zero gamma ray with the logic that it is the least possible number but with the provided hint they progressed in the similar way as the previous group of students. The last group of two students followed a more complicated path. They started out with two as the possible least number the correct answer. Their reasoning was that two particles (electron and positron) were involved so they should give two gamma rays out. Upon being given further hints and cues they followed a progression like the first group of students.

Figure 5.8: Student Variation about Gamma Ray Number



Those students who mentioned one as the number of gamma ray at some point in their progression still had variation in their reasoning. Nine of them held the idea of 'one event means one gamma ray'. The following is an example along this line,

> "Just one should be produced…because you had just one interaction…one interaction gives one gamma ray…"

The other four of them used the idea that something has to be produced because of electron-positron mass disappearance in the process and considered one as the least possible number. For example,

> "There should be one because there is gonna be a number …because it has to be…it is producing gamma ray …so it can't be zero…"

For the students who mentioned two as the least possible number before getting a hint, their reasoning was like the following example.

> "Two…one for each of 'em… one for electron and one for positron… at least two … there is the interaction…how many particles were involved"

After getting the hint about application of the momentum conservation in the process, they came up with the correct answer with better reasoning like the following example.

> "You have to conserve energy and …or you have to conserve momentum…and if the momentum was zero then it has to be equal to zero…so at least two…"

The result of the study indicates that students used complicated pictures of gamma rays, which hindered them to apply the momentum conservation in the annihilation process. The role of the hints and cues were to help students make associations of the annihilation process with momentum and energy conservation. The hints or cues were chosen so that students followed the shortest progression with minimum hints. Based on these results, it could be argued that one way to minimize the number of hints would be to present to the students the gamma ray picture which is useful to understand PET before seeking an answer from them. Another way would be to phrase the hints effectively such that they could apply the conservation laws.

I further asked students about other possible numbers of gamma rays in an event of annihilation to conserve momentum. Most of the students (80%) responded that the gamma rays should be produced in even number to cancel the momentum. Their reasoning was that momenta are cancelled only in pairs. For example,

> "There have to be…almost…there have to be an even number that way…so that for each one produced it may…it will have opposite one it will cancel out so that it doesn't have any movement anywhere"

Upon being asked why can't there be three those students responded like this,

> "…because you would have to have one going in one direction and another going in opposite direction…since all they have the same vectors …these vectors are the same then you can't have three…then they wouldn't cancel"

For this group of students, I regard this as knowledge related difficulty rather than their reasoning based difficulty because they might not have good understanding of vectors. However, the rest of the students used a better understanding of vectors to come up with the correct idea. Upon being asked about the possibility of three gamma rays in light of momentum conservation, a student reported,

> "You have to go them off at perfectly equilateral…equilateral angles…I think it is like 120… if these are 120 then your net momentum would still be zero"

It could be argued that students enrolled in algebra-based physics course may not have skill in vectors and vector representations. But, there were some instances during the interview where they changed their idea of requirement of even number of vectors for the cancellation when a hint was provided. The number of such students was not large (3 out of 12) but they made similar remarks like the above example after recalling learning from their lecture class.

Influence of One Dimensional Collision in Predicting Gamma Rays Direction

'Two in and two out' model of collision is found prevalent among the participants. This study indicates that students' prediction about the direction of gamma rays produced after the electron-positron annihilation is highly influenced by the one-dimensional demonstration they saw in their prior classes. Out of 15 students, 11 students (73%) held the idea of one-dimensional 'two in and two out' model of collision in electron-positron annihilation. Nine of the students (60%) explicitly mentioned that their reasoning was based on the collision cart or air track experiments they saw in their laboratory.

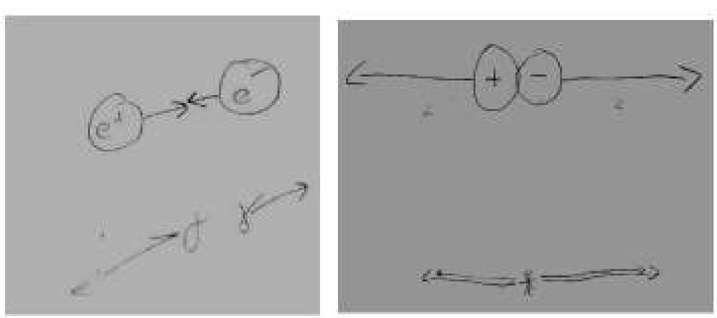
> "An electron and positron collide they produce gamma rays and these gamma rays go in opposite directions…and then like in another activity (refer to the cart activity)…when the carts collided they would also go in the opposite directions…"

The other two students (13%) based their reasoning on everyday experiences of collision of objects.

> "I am thinking that you had … I mean two masses they hit though change to gamma ray and I assume that the gamma rays would do like the mass still there and they bounce off…"

Figure 5.9 that includes the drawing of two different students depicts the student reasoning about the electron-positron annihilation and gamma ray production.

Figure 5.9: Student Drawings of One-Dimensional Annihilation Process



Drawing of one student   Drawing of another student

Four out of 15 students (27%) did not use the one dimensional model but still used the idea of 'two in and two out' but in the two or three dimensional space.

> "On the paper here it is just two dimensional environment…so I can think of two dimension from here to here and drew these various arrows…keeping mind that two dimensional environment…but of course inside the body this event takes place in 3 dimensional environment…so they could move any direction"

Upon further probing many of the students possessing one dimensional collision model they explicitly mentioned that a conservation law should be applied to direction also. They said that the conservation of the line should hold so that the gamma rays should travel back along the same line that the electron and positron traveled before they met to annihilate. This is an example of over application of physics laws. In Chapter 2, I had discussed negative transfer of learning. The students' misapplication of their learning of the cart activity or their everyday experience in the microscopic situation like electron-positron annihilation is a good example of negative transfer.

I did not expect that students enrolled in an introductory level physics would answer all aspects of the electron-positron annihilation correctly. It could be the first time that many of them heard of it. The main point was to know if and how their prior reasoning was hindering their process of learning a novel idea. It is very crucial to note that the mechanical analogies that were very productive in helping students learn various aspects in PET were also counter productive particularly in the area of description of the electron-positron annihilation.

Use of Mechanical Model in Light

Some of the students who participated in this study appeared to use mechanical reasoning about light. While describing the motion of light, they used some resources relevant to motion of mechanical object. For example they used the idea of slowing down of light. Originally, I was thinking that students used the idea of change of speed of light using refractive index model, but later it became clear that they were using a friction model where an object continually slows down. They used terms such as slowing down of light by bumps and hindrance of gamma ray by tumors. I refer to this process as conceptual blending (Fauconnier, 2001; Fauconnier & Turner, 1995) where the students map their knowledge of different domains and explain a phenomena. A typical example along this line is the following statement of a student. She responded this way when I asked her to explain the motion of bits of lights in the light activity.

"It is like Newton's law or one of the laws where an object at rest stays at rest until a force acts upon it…so if you have completely frictionless then it will keep on rolling until something physically stops it …until some force stops it … may be for the light source….may be if it comes off one thing that explodes and reacts may be it can be emitted as wave or could be emitted as particle …and then the only thing we are seeing is that when that particle runs into the plastic it stops…"

Figure 5.10: Students' Association of Light Phenomena with Mechanical Analogy

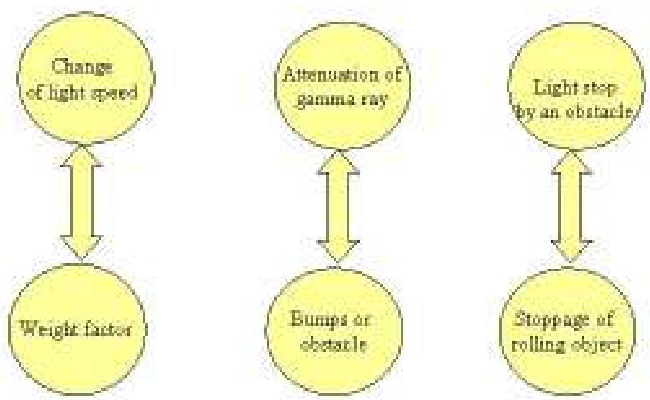


Figure 5.10 presents some of the associations made by the students that support the use of mechanical model of light. I am not sure if the majority of the students would have used this kind of reasoning, because during the interview I did not ask questions intending to elicit students' model about light propagation in medium. Five out of 16 students made these kinds of associations spontaneously. I presented the result here because it might be valuable input for the future research and instruction.

Transfer of a model from one domain to another can sometimes be useful in instruction. For example, students' use of reasoning such as hindrance of gamma ray by tissue can be productive in helping them understand attenuation of gamma rays in PET. This idea is consistent with the anchoring conceptions (Clement et al., 1989).

The Cart Versus the Light Activity

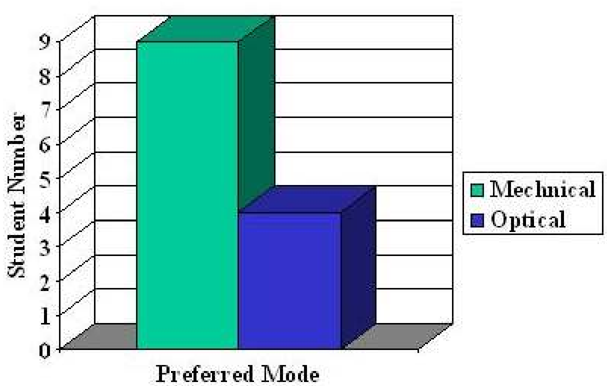
The students were asked to describe which of the activities, the light or the cart, helped them to understand the process of locating hidden events and the PET process. There were two purposes for asking this question. The first was to know which of the activities was more effective and the second was to understand students' perception about different modes of representation that explain the same physical phenomena. About 69% of the students who participated in this study considered that the cart activity was more helpful. In their description, this group of students spontaneously stated that the cart activity is more physical and light activity is more abstract. For example,

> "It is (the cart activity) physical I can see...but in the light rotating (the light activity) I can't see the balls moving…I can see only the end results so it is harder to fully grasp…little bit more abstract I guess… I need to think about in my head but here you can just watch and see what is happening"

However, the other students (31%) who considered the light activity more helpful in locating hidden events and understanding the PET process did not state which of the activities they would consider more concrete. I did not ask them which of the activity they consider concrete and physical. They mainly said that the light activity was good in challenging their central tendency and understanding momentum conservation. This group of students made statements like the following example,

> "The cake one (the light activity) helped me to move away my concepts that the source always has to be at the center…the source in the circle…the different sources within the circle..."

Figure 5.11: Student Preference of the Activities in Learning



The above discussion provides two results. First, the cart activity was more popular among the students, which is shown in Figure 5.11. Second, the majority of the students considered mechanical models more physical and concrete than the optical one. As pedagogical experts, we consider both of them as physical and concrete. In both the activities, students were able to see the end result and work backward to discuss the starting point. Students were engaged in both the activities equally, and they had to make the similar assumptions about speed and direction of motion. The major differences were the representation and the number of dimensions. The cart activity is 1-D while the light activity is 2-D.

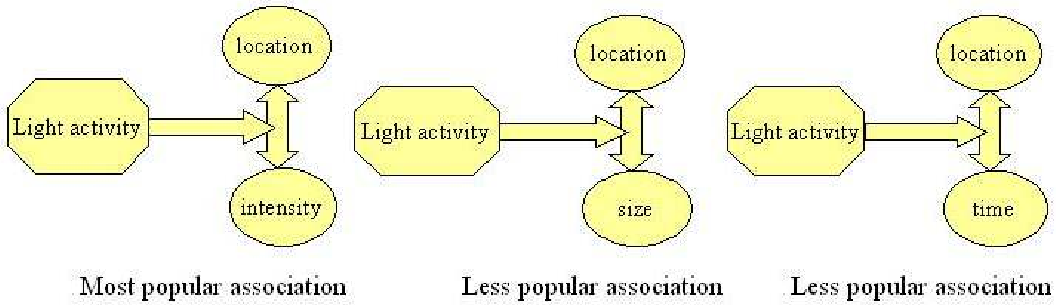
The result indicates that the mechanical activities that provide concrete experience were more effective in student learning. The light activity was successful in challenging some students' ideas and to help them learn an abstract concept. However, based on the result it is difficult to predict what features of the light activity helped the students' learning of abstract idea.

5.6.2 Sequencing Activities

During the first session of the teaching interview the physical models were introduced in two different sequences. First, 11 students had the opportunity to engage in the light activity followed by the cart activity. I labeled this group of students as LC (light and cart) group. For the five students, the cart activity was followed by the light activity. I labeled this group of students as CL (cart and light). I intended to make equal number of students in LC and CL group but it did not happen because of the student unavailability. After the LC experiment was done, I decided to carry out CL experiment and invited an equal number of participants but only five students showed up in the interviews.

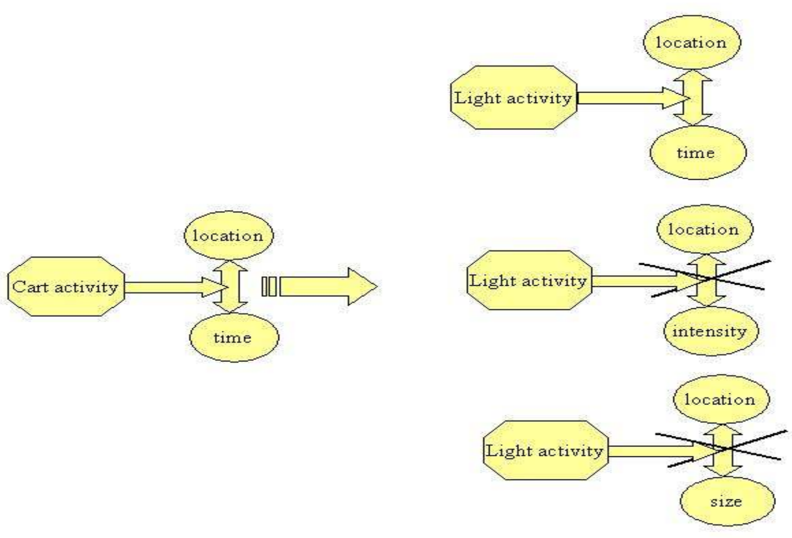
In response to a question on how to locate the event producing light in the light activity, seven out of 11 (64%) from the LC group mentioned that light intensity should be the determining factor whereas two students (18%) mentioned the apparent size of the light. The remaining two students (18%) considered that the time for the light to reach the cylinder would be the determining factor. The different types of association made by students of LC group are shown in Figure 5.12. I labeled the first one as most popular association because a majority of the students in this group made this. The other two associations being made by small student population is labeled as less popular.

Figure 5.12: Association Made in Light Activity by LC Group



The students of the CL group were asked the same question about locating event in the light activity. In response to the question, all five students (100%) considered 'time' to be the relevant factor to locate the event that produces light. Figure 5.13 shows the result in terms of the association made by students. All the students made association of location with time and after that the light activity was introduced. Unlike the LC group, only one association was found in this case.

Figure 5.13: Association Made in Light Activity by CL Group

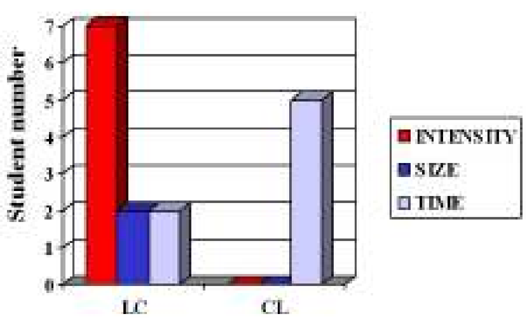


Both the LC and CL groups comprised students from first and second semester of the physics course. The interview transcripts revealed that the cart activity influenced their reasoning in the light activity. The following student quote is an example, "Ok…then we could do the exact same way (points to the cart activity)…if we find, you know, how long the line is you find the distance based on the time difference…so this one turned on first…so the difference between the time…very similar to how we did that (cart)"

The sequencing effect can be explained on the framework of the resource-based cognitive model of reasoning. It can be speculated that most of the students in the second group (CL) activated their resource of 'time' as being associated with the 'location' of the event. This activation was apparently based on the cart activity. Shortly afterward, they were introduced to the light activity. Apparently, the associations they made between 'time' and 'location' with the cart activity were so strong that it was able to activate the 'time' resource to make similar association in the context of the light activity. But, for first group of students they didn't have an opportunity to make an association of 'time' with 'location' with the aid of cart activity before doing the light activity. So, they activated their resources from their everyday life experiences where they usually locate lights based on their intensity or size. Thus, they made the association of 'location' with 'intensity' or with 'size'. This group of students appeared to have activated the p-prim (diSessa, 1993)'closer is brighter' and 'closer is bigger' to conclude that the location should be determined by the intensity or size of the lights. This p-prim-based association was apparently so strong that the association between 'time' and 'location' could not displace it. In other words, the sequence of the activities CL vs. LC made a difference in the activation of knowledge resources by these students as they explained this activity.

Figure 5.14 gives the comparison of the number of students who considered different factors while locating the events.

Figure 5.14: Comparison of the Types of Association in LC and CL



The students of LC group after being introduced to the cart activity were engaged in the drawing part in the light activity to locate the group of events. The goal was to see if they change their original idea to locate events. Two out of 11 (18%) in this group who already considered 'time' were still rigid on their reasoning. Another seven of them (64%) changed their idea and said that they would consider 'time' to determine the location. Remaining two students (18%) of this group who held the idea of 'intensity' still did not change their idea. Below is an example of a statement of a student who considered 'intensity' originally changed to 'time' after doing the cart activity.

> "I would move the source either one way or the other depending on…each line…say for this particular line …if it hits this one first then I would move the source little bit closer to this side than this side…"

Many students expressed their views that it was difficult for them to realize that time should be measured in the context of light because of its speed. They stated that after doing the cart activity they could take the idea from the cart activity and apply in the light activity. Upon being asked the reason of relying on 'time' in the light activity one student stated that

> "From that activity (cart activity) …you could…I guess it depends on the time …the time you saw each of the events and then you will be able to figure out where exactly the event occurred along that line…yeah…"

The target idea of this activity was 'time determines location'. It is apparent from this study, that the students could easily apply that idea in the context of the cart activity. I wanted to help them apply the same idea in the light activity also because I wanted them to realize that consideration of 'time' is equally relevant in small time scale involving light. Another reason was that PET technology involves gamma ray detection in coincidence. The detection of gamma ray in PET can be made understandable if students understand the light activity. Detection of gamma ray in PET is two and three-dimensional problem. The cart activity on the other hand is one-dimensional. The light activity, which is a two-dimensional experiment, is closer to real PET scanner in that sense also.

The result from the sequencing of activities indicated that students used the target idea in light activity when the cart activity was introduced first. I originally thought that sequencing the light activity before the cart activity could be more logical. The argument was that the light activity needs statistical consideration about event locations whereas the cart activity gives more accurate location for a single event. It would be logical to go from an approximate to accurate method. Even from the historical perspective, I decided to use that sequencing because the light activity explains the traditional PET and the cart activity describes the more recent time of flight PET (TOFPET). But this study showed that experts' perspectives do not always work in student learning and we need to focus more on instructional strategies that students find logical.

5.6.3 Transfer of Learning from the Physical Models to PET

To study transfer of learning, two sessions were used in the teaching interviews. The first served as a learning experience. The second session, where the students were provided with the PET imaging related problems, was a transfer session. Students were not told during the first session about the second session and the spacing between the learning session and the transfer session was 5-7days long.

From the encoding specificity (Bruning et al., 2004) perspective in cognitive psychology, transfer of learning is deemed easy if the problem structures are superficially similar in the learning stage and the transfer stage. Contrary to this, some researchers (Goldstone & Sakamoto, 2003) reported that increasing concreteness of the problem does not promote transfer of abstract ideas. The physical models used in the first session were developed to facilitate transfer of abstract ideas from one context to another. The activities in the learning and transfer contexts were therefore intended to be different at the superficial level but similar at an abstract level. For the learning session, structurally simple hands-on activities were designed with underlying abstract physics concepts. On the other hand, the transfer session used the problems that were similar to problems in the learning session at an abstract level but in different contexts and modes of presentation.

The main objective of the investigation was to see if and how students make association of the activities in the two sessions. For the context of this research, the resource-based association framework (Rebello et al., 2005) was considered to define the transfer of learning. Unlike most of the traditional methods this research does not assess transfer in terms of degree or numerical basis rather it assesses transfer as the types of association.

The study showed that most of the students who participated in this study transferred ideas from the activities of the first session to the second session to understand the image construction process in PET. Based on the students' responses to the question, the occurrence of transfer is classified into three categories (four categories if no transfer is included).

Spontaneous Transfer (ST)

If students immediately related PET problems with the activities of the first session, the transfer is labeled as spontaneous (ST). The following conversation between the interviewer and a student provides an example of spontaneous transfer.

> Interviewer: "How will the PET machine be able to determine the exact location of annihilation in the brain?"
>
> Student: "It made me think very similar to what we have with the carts on the track going and could not see… I couldn't see exactly when it released and figured out the distance where it was….so in here where the annihilation taking place might be close to one…one side of the body in this side of my head or something that one detector over here gonna detect faster than over there…exactly obviously 180 degrees…but use that time difference and determine the exact location where that is taking place…"

Figure 5.15: Association in ST

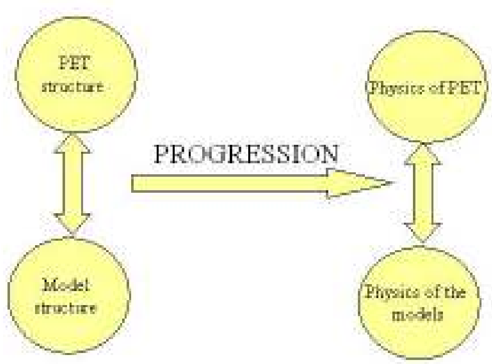


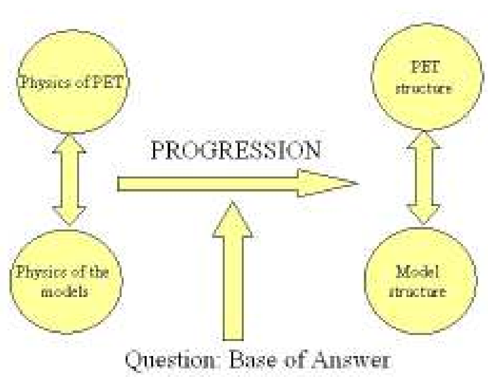
Figure 5.15 shows two steps involved in the ST transfer. In terms of association, they associated problem structures followed by the association of physics ideas. Since they made the progression within the same statement during the interview and no further questioning or hint was needed, this transfer is spontaneous.

Semi-Spontaneous Transfer (SST)

If students related PET back to the activities of the first session upon being asked the reason for their answer, the transfer is called semi-spontaneous (SST). This group of students provided an appropriate response by themselves. However, in those responses they did not reflect back to the activities in the first session or give specific reasons for their responses. They were further probed to investigate if they were able to associate the relevant physics ideas of the physical models with the PET problem. The probing was done by a question about the basis of their reasoning. For example:

> Interviewer: "How will the PET machine be able to determine the exact location of annihilation in the brain?"
>
> Student: "You probably need to measure the speed of the rays getting to the detectors because if it took place at dead center right at the middle of your head then probably it goes straight down then they will reach at the detectors at the same time…if it took place over here then the one in this side will get the ray sooner…and I don't know if the intensity is important of gamma ray but I would assume the one that travels the least distance probably need to be more intense…but I don't know for sure …. I don't know much about it…gamma rays"
>
> Interviewer: What caused you to answer in that way?
>
> Student: "Kind of like we talked about last time. The fact that … you can have something happen…and you know happen on one side that gonna get first ….if it …it won't always happen at the dead center…like the reaction doesn't always happen at dead center….if it happens to the right or the left the light gonna turn on sooner on one side than the other …it doesn't always have to have happen right dead center…it can happen anywhere along the line you just need to measure which one hits it faster…"

Figure 5.16: Association in SST



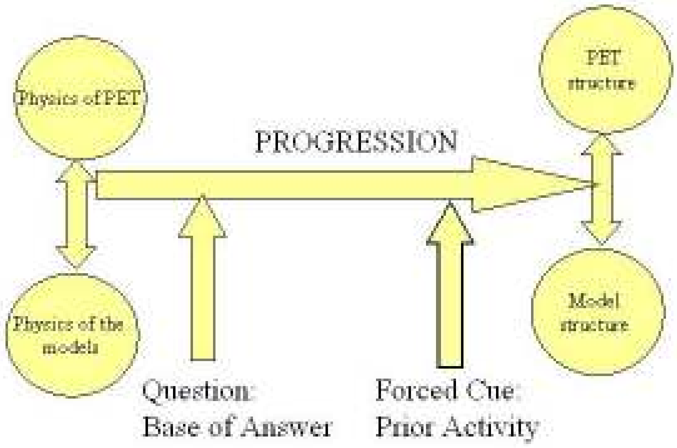
The Figure 5.16 shows the associations made in SST. However, it cannot be claimed that it was the actual sequence of association taken place in their mental process. I am reporting the results based on the conversation. In terms of learning, ST and SST group do not have much difference because both the groups came up with the appropriate reasoning. Other than the difference in expressed sequence, they had made similar type of association and can be argued that both the groups transferred from the first session to the second. Another reason for labeling it different from ST is that it needed an extra external input in the form of a question.

Non-Spontaneous Transfer (NST)

The third category is non-spontaneous transfer (NST). The students are categorized into this group if they related PET with the first session only after being asked if they had seen a situation similar to PET somewhere before. This group of students came up with the somewhat appropriate answer without associating with any of the activities in the first session. Even after asking the question similar to the case of SST, they did not to relate back to the activities of first session. Finally, they needed a strong cue to relate to one of the activities in the first session. The following segment of conversation gives the idea of NST.

> Interviewer: “How will the PET machine be able to determine the exact location of annihilation in the brain?”
>
> Student: “They were going in opposite directions and so depending on when they hit and how fast they are going you can use that information to find out where the…where it started…so if one hits this one before hits that one …then you know that it is closer to over this side…because they were traveling with the same speed after the collision so…you could use that to figure out the…”
>
> Interviewer: What caused you to answer in that way?
>
> Student: “I knew there was a collision…and I knew that these detected the ray and the rays are produced from the collision …I knew that’s how we can figure that out”
>
> Interviewer: “Did any prior activity help to answer this?”
>
> Student: “Last week when we did the cake exercise (the light activity) trying to figure out the source of light that kinda helped too…”

Figure 5.17: Association in NST



In terms of the performance, students of NST gave slightly less appropriate answer than the above two groups. I suspect if the activities in the first session were effective for this group of students in triggering their conceptual resources relevant to the physics of PET. As indicated in Figure 5.17, it took two extra steps of hints as compared to ST to make them associate with the activities of the first session therefore I labeled it as NST.

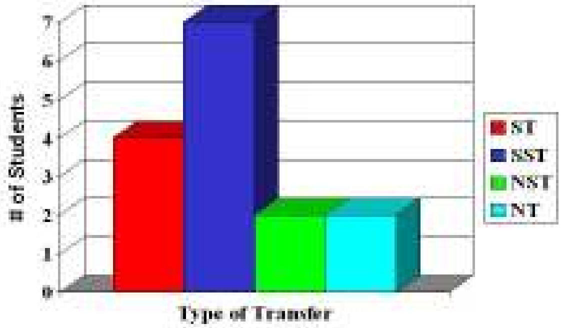
No Transfer (NT)

There were some instances in which very few of the students did not transfer at all from the first session to the second session. Here is an example.

> Interviewer: "(after introducing the picture of coincidence detection) How does the machine get the exact location of annihilation?"
>
> Student: "I can tell it …can tell about here (detector)…. can't tell how far from here …I can't tell how to get the exact location… because I never saw this machine and don't know how it works…"

For this group of students, none of the hints worked and they never came up with appropriate reasoning to address the PET problem. They always argued that they never saw a problem similar to PET in any of their prior activities or classes. They were even reluctant to associate the cart and the light activity with any of the features that could describe PET.

Figure 5.18: Statistics On Types Of Transfer



The distribution of the students exhibiting different kind of transfer is shown in Figure 5.18. The most popular type of transfer in this study was SST, which was found among 47 % of the participants. The second largest population (27 %) exhibited ST transfer. Only 13 % of students demonstrated NST transfer, and another 13 % of students' responses were in the NT category.

At the end of the second session, students were asked to reflect on the activities and compare the activities of two sessions. Out of 15 students 10 (67 %) reported that the first session was useful in the second session to help them solve the problem faster. Table 5.3 shows that all four students of ST group found the first session helpful in the second session. The students who did not find the first session useful in the second session were in the NST and NT categories.

Table 5.3: Students Considering the Role of the First Session in the Second Session

Type of Transfer	Helpful	Not helpful
ST	4	
SST	5	1
NST	1	2
NT		2

Upon being asked what would be the effect in their second session if had not done the first session the students remarked like the following example,

> "I could figure out somehow but it would have taken lot longer for me to catch on …the box with the light on …that really helped because then…when you showed me that circle (PET detector) I instantly related that box to that circle …and how do you determine where the event took place in the box instantly I remembered the circle and how to determine where the event so I knew exactly where we were going and determining where the annihilation took place in the body"

The students' statements like the above suggest that the first session helped them to complete task of second session in short time. This indicates the transfer of learning from the physical models to the PET problems from some researchers' perspective who consider the occurrence of learning transfer if students complete the transfer task in shorter amount of time (Warnakulasooriya & Pritchard, 2006).

Unlike many of the earlier studies (Chen & Daehler, 1989; Chen *et al.*, 1995; Gick, 1980), this research shows significant transfer from learning context (first session) to transfer context (second session). It could, of course, be argued that the students already had some ideas about the transfer context due to hints or cues from the learning session. But, it is encouraging that they made an association with the activities of the first session with those of the second session without any hints in spite of the different problem structure in the two sessions. The students were not told to use the activities in the learning session while addressing the issues present in the transfer session but they themselves built or changed their ideas based on their previous interactions with the physical models. This result suggests that the exercise helped them to construct ideas by active learning and eventually led them to apply newly learned concepts in the transfer task.

5.7 Chapter Summary

In this chapter, I described the investigation of student learning and learning transfer using teaching interview methodology. The teaching interview session provided the constructivist-learning situation where students constructed and tested their knowledge in interactive learning environment. To investigate the dynamics of learning, I carefully looked at the progression and association of student ideas.

In various sections in results and discussion, I provided the description and assessment of learning transfer. I regard the section on student reasoning as the description of the transfer of learning. The main focus of the section was the students' transfer of reasoning based on prior experiences including everyday experience. In the sequencing activities, I described another type of transfer where students used ideas of one activity to explain the other activity. Finally, I presented the transfer from the physical models to the PET problems in another section. The occurrences of transfer were categorized into three types based on the type of associations. I regard the transfer presented in the last section as the assessment of transfer.

At the beginning of the chapter, I posed three research questions. In response to the first research question, the results of this study showed that the introductory physics students who participated in this study rely on everyday experiences even when dealing with complex physics problems. They also appear to transfer their learning from familiar physics experiments to new situations.

In reply to the second research question, the analysis of the activities of two groups of students showed the importance of sequencing different activities. Based upon these results, we can suggest that the sequence of the activities has an important role in activating different conceptual resources. This result has important implications in designing teaching materials.

The answer of the final research question is that students indeed transfer their learning from the physical models to understand the technology of PET. It was discussed that facilitating spontaneous or semi-spontaneous transfer maximizes the student learning. Depending upon the ideas we want students to apply in a new situation, we can decide where and when an activity should be introduced to facilitate spontaneous transfer for a majority of students.

CHAPTER 6 - Role of Group Interaction in Learning and Transfer of Learning

6.1 Introduction

This chapter presents the investigation of the social influences on learning and on learning transfer of physics. Group teaching interviews used in this phase of the study were social settings in which a rich interaction took place between student-student and student-teacher (interviewer). The interviewer with the aid of the physical models provided scaffolding. The research systemizes the students' ideas and idea progressions during group interactions. By the use of the mock laboratory setting this phase of the research effort attempts to understand the classroom dynamics. This insight can inform if the teaching activities used in the interview are suitable to use in the real classroom setting.

6.2 Research Questions

The goal of this phase of research was to answer the following questions.

1. What is the effect of scaffolding provided to facilitate learning?
2. What is the effect of group interactions on
    a) Activation of students' cognitive resources?
    b) Facilitation of learning transfer using the physical models?

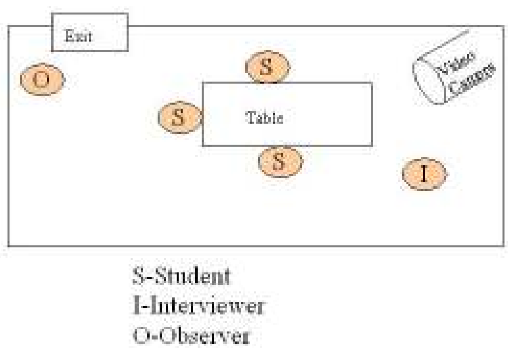
The term scaffolding in the first research question refers to the hints, cues and questions presented to the students during the interview. I am mainly interested in investigating the role of sequencing hints and phrasing the questions. The student performance is assessed with the number of hints and the strength of hints. In this part the research question is answered in terms of the comparison with the results presented in the previous chapter.

The first part of second research question concentrates on the group scaffolding in activation of peer cognitive resources. The research on individual interviews presented in the last chapter showed the types of cognitive resources students use while interacting with the physical models. I was interested in further exploration to understand if and how students use such resources within the contexts of group interaction. I presented the result of the types of transfer on individual teaching interview in the previous chapter. The major interest of the second part of the second research question is to look at the types of transfer that occur in the context of group interactions.

6.3 Research Setting

This study was carried out during the fall of 2006. In all, 21 students in 9 groups participated in the study. The student population of 10 females and 11 males were enrolled in General Physics. They were chosen randomly by sending them an e-mail requesting participation. They participated in two sessions of the teaching interview each about one hour long and were offered $20 for the participation. They were mainly pre-medicine, pre-veterinary medicine, statistics, biology, and geology majors, and they had a high school physics background.

Figure 6.1: Seating Arrangement in Group Teaching Interview



Group teaching interviews were conducted in order to look at students' dynamic construction of knowledge when working with peers. There were six groups of two and three groups of three students who participated in teaching interview sessions. The students in the group sat such that they could see each other with the interviewer observing their activities. The seating arrangement is as shown in Figure 6.1. This seating arrangement was very suitable for the student-student interaction. It also provided the suitable arrangement for videotaping the activities without capturing the faces of any of the students. Before beginning the sessions, I went through exactly same process as in the individual interviews to address the IRB issues. The session began only after they signed the consent form.

6.4 Teaching Interview Activities and Format

The group teaching activities used the same sets of activities as described in section 5.4.4 and 5.4.5 for the individual teaching interview. They interacted with the physical models during the first session of the interview whereas in the second session they were engaged with the discussion of problems related to PET technology. The major questions and activity sequence used in this phase of the research were similar to that in the last phase. Some of the questions were phrased differently based on the results of the individual interview. The sequence of the cart followed by the light activity (CL) was used for all the groups because the results of the last phase of the research showed the activation of the reasonable students resources with this sequence. The sequence of the activities in the second session used in the group interview was identical to that in individual interview.

The format of presentation of activities and questions in this phase was different as compared to the last one. Rather than interviewer asking them questions directly, they were provided worksheets containing activity introduction, description and questions. For the details of the activities in the worksheet please refer Appendix J. There was minimal interviewer intervention, and the interviewer's role was like a moderator of the sessions.

The students were instructed that they could go to the next part of the session only when they finish activities and questions presented within a page. This instruction was very important because in some cases the answers of the earlier set of activities were used in the next part of the session. If they had read the later set of activities and questions before completing the former, it would influence the answers of the former.

I adapted peer instruction format in the interviews (Mazur, 1997). Typically, students observed the teaching activities and read the questions in the worksheets. They were first asked to think individually and to write or draw personal responses on the provided worksheets. Then they discussed what they wrote and what they thought with the other group members. The goal of this group discussion was to come up with the best answers through consensus. If they did not reach the consensus, they asked me questions. In such cases instead of telling them the target idea, I gave hints or cues to help them test their own ideas. Then they had a further round of discussions until they convinced each other. The peer and interviewer scaffolding helped them to change their answers if they realized that their original answer was not appropriate.

One of the roles of the interviewer was to adjust the duration of the activities. I, as the interviewer, was active mainly to start up and close of a set of activities and to create transitions among activities. Typically, I instructed them to discuss an issue to elicit their understanding. If interesting ideas emerged from the students' discussion, then I asked further probing questions. Apart from this, I also encouraged them to examine their own thinking and helped them to come up with the best answer based on their current knowledge and experiences. Whenever they did not come up with any idea about a question or they need further clarification on the worksheet write up, they asked me. In such cases, I gave explanations, hints or cues as scaffolding. Besides this, when they were not sure about their answer, I referred to the activities and offered the group members methods to test their ideas. Once the group consensus was reached, I challenged their idea if it was not the target idea and asked for further clarification if it was the scientific idea. In both cases, I tried not to let them know if their answer was right or wrong. After a sufficient discussion in a set of questions, they were told to move to the next set of questions.

Some of the teaching sessions were observed by some of my colleagues. They gave me useful suggestions and feedback for the improvement of the sessions.

6.5 Data Analysis

The data analysis followed the most of the steps with Colaizzi's phenomenological analysis technique. The interviews were video and audio taped. The transcription of each of the teaching interview sessions consisted of the statements, non-verbal gestures and sketches of the interviewees. The transcript also contained the interviewer's questions, hints and prompts to show how students responded to these hints and cues. The students' worksheets served as another data source. The students' worksheet responses were mixed with the interview transcript in a tabulated form. Significant statements were then extracted from the transcript and the work sheets.

An association diagram was made from the significant statements using the two-level framework. In addition to this a progression table was constructed to look at how students' ideas progressed over several steps. The progression table is very useful in this research to count the number of steps that the students went through, the number of hints provided to the groups, and to look at the nature of student reasoning (qualitative or quantitative). The table consisted of three rows. The students' responses were entered in the first row and the corresponding students' label in the second row. The third row showed the inputs given to the students. A sample of the progression table is shown in Table 6.1.

Table 6.1: An Example of Progression Table

CATEGORY 6: LOCATION OF EXPLOSION ON A LINE

IDEA	Explosion is in the middle of the line	Why cannot it anywhere inside the circle?	The explosion parts should go in all directions…lights exploding	Thought about continuous emission of light by explosion
STUDENT	A3	A2	A2	A2
INPUT	What is the location of explosion			Something else explodes giving the lights

Several samples of progression tables (Appendix M) were sent to five physics education researchers at KSU to code each of the steps of the progression independently. The researchers' filled out tables were collected and tabulated to check the agreements (please refer the Appendix N). Only those steps in the progression diagram were considered for the further analysis if there was an agreement of 67% or above among the six researchers (including me).

I then examined the progression and associations constructed by the group of students in the different segments of the teaching interview. A common theme for each category was extracted after examining the progressions and associations made by different groups of students. A description of each theme was then prepared and based on the different progression and associations that the student groups generated.

The analysis process presented above is consistent with the six steps of Colaizzi's phenomenological analysis technique. I could not perform the seventh step of the technique known as member check. I could not take the findings of the results to the participating students because of the unavailability of the students. However, while performing the steps one through six I tried to make sure that there was no fabrication or omission of students' ideas. I requested that some of my colleagues and advisors watch videos of some of the interviews independently, and I cross-examined my analysis of student responses. The systematic data analysis also went through the inter-rater reliability test among five researchers beside myself.

I adapted the strategies of other researchers (Murray & Arroyo, 2002; Warnakulasooriya & Pritchard, 2006) to measure the task performance of students. Warnakulasooriya & Pritchard, (2006) measured students' learning transfer by counting the number of hints provided whereas Murray & Arroyo, (2002) quantified the task performance and ZPD (Zone of Proximal Development) by counting the number of problem steps and hints provided. Murray has further given different numerical values for different hint strengths to quantify the results. I also tried to provide different strengths to different types of hints but there was not sufficient agreement among the six researchers (including me) to classify the strengths of the hints. So, I gave all hints an equal weight and just counted the number of hints provided and number of steps students proceeded to look at their performance. However, there were few instances where a fair agreement was reached to decide the strength of hints. These cases will be described separately later. I extended the idea to count the number of qualitative and quantitative reasoning steps made by students to see if the ratio of number of qualitative to quantitative reasoning steps correlates with students' task accomplishments.

6.6 Results and Discussion

In this section I present students' knowledge construction process in the context of group interaction. I discuss the idea progression of students within each group and the overall theme extracted by comparing the similar progression in various groups. The role of the group interaction for the students' idea progression is described. The results of the students' performance in individual teaching interviews are compared with those in the group interviews. In addition, the influence of scaffolding provided in the form of hints or question is presented. Finally, the exploration on the types of transfer in the context of group learning is discussed.

6.6.1 Role of Peer Interaction to Change Students' Reasoning

In this section, I present students' reasoning and problem solving approaches related to locating hidden events. A comparative study is presented on students' performance while working in the groups versus individual efforts. In each of the categories, the progression diagram, association diagram and the provided scaffoldings are presented to support the description.

Approach of Event Location in a Track

In the hidden carts activity, the number of steps and the direction of students' progression were significantly different in different groups. In addition, the number of hints provided by the interviewer also varied in different groups. I classify the student groups into three sets. The first set of groups could solve the problem quantitatively, the second set was able to develop a qualitatively correct approach without being able to complete the task quantitatively, and the third set never came up with correct ideas in spite of several scaffoldings. I present an example of each set on how they progressed with the related association diagram. In this case, I explicitly indicate in the input row if the scaffolding is from peers or interviewer. If it is from peers, I put the arrow as described in the earlier category, and to indicate the scaffolding from interviewer I denote by IS and arrow in the direction of students who got the scaffolding.

Table 6.2: Quantitative Approach in Cart Release Location

Harry	Location $\updownarrow$ Speed, time	Location $\updownarrow$ External force on carts	Location $\updownarrow$ Velocity equation	Location $\updownarrow$ d=vt
	(IS) $\uparrow$ how to find location?	$\downarrow$	(IS) $\uparrow$ what equation used? $\downarrow$	$\downarrow$
Adriano	Location $\updownarrow$ Momentum	Location $\updownarrow$ Time difference	Location $\updownarrow$ Length of track	Distance one cart traveled more $\updownarrow$ d=vt
				$\uparrow$
Leonardo				Ask how to use the equation

Table 6.2 presents an example of a progression and association diagram for a group of three students. Harry is sophomore majoring in political science, Adriano and Leonardo (all are not real names) are also sophomores but majoring in pre-veterinary medicine. Table 6.2 shows how they interacted with each other and progressed to solve the problem of finding the location of carts release.

I regarded the students groups as completing the quantitative determination of the location if they identified the time difference and speed of carts as the variables, put the variables in the equation d=vt, and interpreted the numerical result accurately.

Table 6.3 is an example where students completed the qualitative approach of determination of location. Students of this set were able to identify the variables without being able to put them in an equation and get the numerical result. Heather and Daniel (both virtual names), whose description is given earlier in another context, were the students making this type of progression.

Table 6.3: Qualitative Locating Approach

Heather	Location ↕ Velocity, mass, force	Location ↕ Velocity, time	Timing ↕ Time from release	Timing ↕ Time difference	Difference between carts ↕ Displacement
Input	↑	↑	(IS) How to measure time? ↑	(IS) Do not know when released ↑	↓
Daniel	Location ↕ Velocity	Location ↕ Velocity, distance	Timing ↕ Stopwatch	Timing ↕ Time from release	Difference in distance ↕ Speed and time

The student groups that could not locate the event with either approach are put under the unsuccessful set. The example shown in Table 6.4 is a group of three students. Jeffery is Junior in chemistry, Nathan is a junior in chemistry and Matt is senior in physical science (all pseudonyms).

Table 6.4: Unsuccessful in Locating Cart Release

Jeffery	Location ↔ Mass	Location ↔ Time		Time difference ↔ Additional time of travel of one cart
Input		↓		↑
Nathan		Location ↔ Time of release	Location ↔ Time	Time difference ↔ Length of track
Input			(IS) When did you start the watch ↑ ↓	
Matt	Location ↔ Distance		Timing ↔ Time of release	

Five groups of students (11 students) were able to get the numerical results and interpret them correctly. The student groups took 18 to 24 steps, and the interviewer provided 6 to 16 hints to complete the task. The ratio of number of qualitative to quantitative reasoning steps ranges from 1.2- 2.

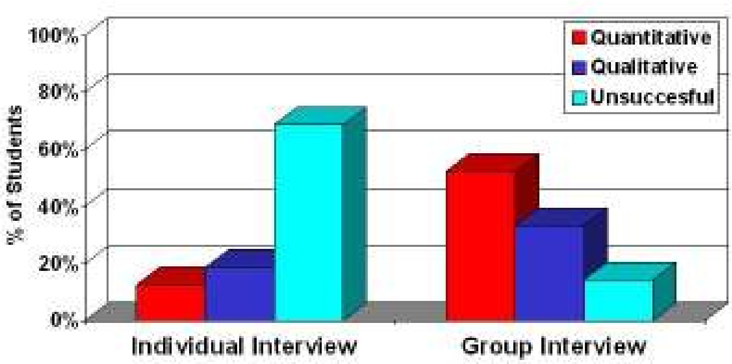
Three groups of students (7 students) were successful in the qualitative task. Students engaged in 17 to19 steps and 4 to 11 hints were required to accomplish the task. The ratio of number of qualitative to quantitative reasoning steps ranges from 1.1-1.8.

In the activity of locating carts 3 students (1 group) were unsuccessful. The students were engaged in 23 steps altogether where 8 hints were provided by the interviewer. The students were involved in 7 qualitative and 11 quantitative steps (ratio 0.6) in the entire task (in five steps there was no agreement with the researchers about whether the steps were qualitative or quantitative).

From the above results, it can be deduced that students of the ‘quantitative group’ engaged in relatively more steps to complete the task as compared to the ‘qualitative group’ but it was not the interviewer who stopped ‘qualitative group’ from proceeding further. It is interesting to note that students of ‘unsuccessful group’ took as many steps as ‘quantitative groups’. The ratio of qualitative reasoning to quantitative reasoning in both the qualitative and quantitative group is more or less the same. However, it is evident that students of ‘unsuccessful group’ were engaged in more quantitative steps.

Student performance in the group teaching interviews was significantly better than that in individual teaching interviews. Figure 6.2 shows the statistics of students’ performance in two cases. As discussed earlier, a majority of the students were successful in quantitative task while engaged in the groups. On the other hand, 11 out of 16 students (68.75%) engaged in the individual teaching interviews were not successful in making any kind of approach to solve the problem. Only two students (12.5%) were able to complete the task quantitatively and the remaining three students (18.75%) could complete the task with qualitative reasoning successfully.

Figure 6.2: Students Performance in Locating Cart Release



The following two examples give ideas on the students reasoning and the student progression during individual and group teaching interviews. All the names used in the discussion are not real. First I present an example of an individual interview where a student was unsuccessful in the task.

Interviewer: To find the exact location what information do you wanna know?

Sharon: The speed of the carts… and the distance they traveled….

Interviewer: Do you need anything more?

Sharon: I need time

Interviewer: Time, how do you measure?

Sharon: Both of them… time from when you released.

Interviewer: But you don't know when I released

Sharon: So, the speed and the time…

Interviewer: How to start time?

Sharon: Distance and ….I don't know

The following is an excerpt from a group teaching interview. The students were able to complete the task at the qualitative level without an extra hint or interviewer scaffolding.

Worksheet question: What information do you need to find the exact location

Beth: We need the velocity…then the

Ruth: Distance…total distance

Interviewer: Do you need anything more?

Ruth: Time

Interviewer: How do you measure the time

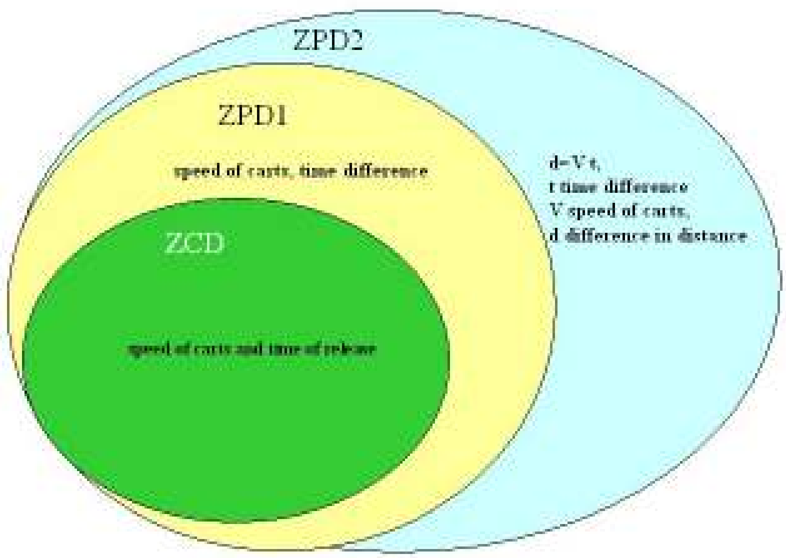
Beth: We have to know when…

Ruth: When you released it…difference between it hits…difference…

Beth: Difference between the time

In both the examples, the total number of steps is almost equal (9 and 10). The questions are phrased in a similar way. The first few steps go exactly parallel. I consider the statement made by Beth '…we have to know when…' as the turning point between the two sets of the interview excerpts. Beth might have similar reasoning as Sharon of individual interview case but Ruth twisted it and brought up the idea of 'difference of time'. This immediately triggered an idea for Beth, and she also constructed the similar idea. That is how students of comparable knowledge background can help each other by activating one another's relevant conceptual resources.

Figure 6.3: Vygotsky's Zone of Proximal Development in Locating Cart Release



Students' performance difference in different contexts can be explained on the theoretical basis of Vygotsky's zone of proximal development. Without any scaffolding, most of the students (68.75%) in the individual teaching interview considered the speed of carts and the time of release as the information required to find the location of carts release. This is what the students could accomplish without any help from more knowledgeable others. For this group of students, the ZCD (zone of current development) is their ability in identifying speed of carts and time of release in the context of locating the event. I provided students stop watches and told them that there is an alternative way to measure times other than starting the watch when the carts are released. This hint helped them to realize that time between two carts hitting the end should be measured. Seven out of 11 students who were unsuccessful in individual interviews were moved this way to another zone, ZPD1. By providing scaffolding such as giving the numerical values of speed and time difference, two students of this group were able to use the equation d=vt in event location in the cart activity. I consider that those students expanded their area up to ZPD2 by interviewer scaffolding.

It was difficult to identify the ZCD of individual students who participated in the group interviews through interview transcripts because of the immediate group discussions. Assuming the similar physics background and random selection of students who participated in both types of interview, it could be argued that the ZCD of individual students who participated in group interview could be similar as reported in results of individual interview. The conversation between Beth and Ruth presented above shows that at least Beth might be in the group of students who could just reason up to ‘speed and time of release’ to find the location.

To know more detail about individuals’ ZCD in the group interviews I looked at each student’s worksheet. Since the students were asked to complete the worksheets before they discussed it, the response could provide me more information on what the students thought individually before they engaged in the group discussion. This way I could estimate the ZCD of each of them. Based on the students’ completed worksheets I found that 12 out of 21 students (72%) wrote in their worksheet that speed of carts, time of travel of each carts and track length needed to be measured. The rest of the students (28%) explicitly wrote that time difference and speed of carts should be determined. Once the discussion started, all but one group immediately realized the need to find the time difference rather than the time of travel from the cart released location. This way 3 groups (7 students) expanded their knowledge up to ZPD 1 as shown in Figure 6.3 and 5 groups expanded their zone even beyond that to get to ZPD 2.

The interviewer in the individual interviews scaffolded almost 69 % of the students to take them to ZPD 1 or ZPD2. The peer scaffolding was responsible to move 72% in the group interview. The results of the individual versus group interview showed that more students were successful through peer scaffolding than through interviewer scaffolding to do the quantitative task (53% versus 13%). Even though the students constructed their knowledge socially with the help of others in both the cases, the peers were more effective ‘more knowledgeable others’ than the interviewer. Vygostky (1978) pointed out that language and culture are the frameworks through which humans experience, communicate, and understand reality. If the less capable learner and the ‘more knowledgeable others’ share similar conceptual schemes to explain a physical situation, co-construction of cognitive structures is easier.

One of the epistemological beliefs of students about learning physics is that *knowledge is propagated stuff* (Hammer et al., 2005). I speculate that this mode is activated more when the student is highly influenced by the presence of a physics teacher. In such situations they look for the facts, search for the equations and try to get the quantitative result as soon as possible. This leads them to be unsuccessful in both qualitative and quantitative modes of the task. On the other hand, when they work with peers, they search for the alternative ideas in non-threatening environment, which facilitates students' qualitative reasoning. Therefore, other modes of epistemological belief such as *knowledge is free creation* or *knowledge is fabricated stuff* (Hammer et al., 2005) are promoted in such cases. Students, rather than looking for an exact answer or the equation, try to construct ideas themselves with the help of peers. This ultimately leads them to solve the problems successfully.

Locating Simulated Explosion (Light Activity)

Two types of variations are discussed within this category. The first is students' central and non-central ideas and the second is the student consideration of event locating factors. The following is an example of a group of students of 'non-central' tendency and who considered 'time' to locate an event along a line. The students involved are Carol, Mark and Saffron (all pseudonyms). Carol is junior in pre-medicine, Mark is senior in microbiology and Saffron is junior in biology.

> Interviewer: Where did the explosion bits start?
>
> Mark: Anywhere inside the circle…
>
> Carol: Yeah… bits start anywhere along this line (line between two lights)…
>
> Saffron: True…we don't know the exact…anywhere along this line
>
> Interviewer: Why should the event be along that line?
>
> Carol: We know they are two pieces
>
> Saffron: We have only two and we assume no other velocity affected…so they explode in exactly opposite

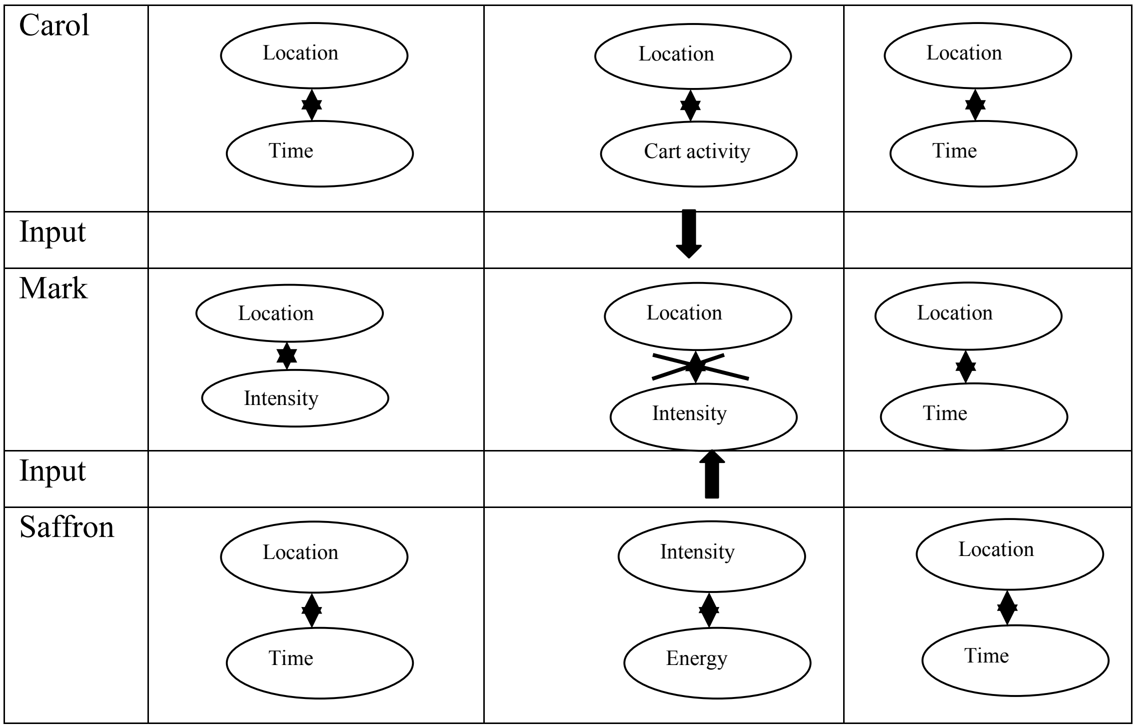
The students unanimously decided that the event could be anywhere along the line. This is an example of peer scaffolding where the students are building upon each other's idea to construct knowledge. The role of the interviewer or worksheet question is to help them move from one set of discussion to another. A student of the group (Mark) started with the idea that the event could be anywhere inside the circle but the rest of the group built with that idea and came to the final decision that the event could be anywhere along the line. This is the target idea of this part of the task.

Below is another segment of the transcript that shows the students' discussion about locating event along the line.

> Worksheet question: What can you tell about the location of the event?
>
> Carol: It's gonna be right middle of the two points…well not necessarily in the middle…
>
> Saffron: Oh… I guess we wouldn't know which one…
>
> Carol: Light at the same time
>
> Mark: I got you…do we need to see intensity
>
> Saffron: Just same thing as cart (cart activity) whichever gets first…that with light I mean…
>
> Mark: It is like closer to one side…the light is brighter in this side…that's what I guess…
>
> Carol: Intensity tells more about the energy of the light than location…so that we can do whole stopwatch thing on one hit before another one hit
>
> Saffron: Yeah… theoretically

The role of the peer scaffolding in construction of knowledge is evident from the above discussion (please see Table 6.5). In response to a question in the worksheet, the students continued their discussion about the factors that need to be considered to locate the event along the line. Carol automatically thought that it could be at the middle of the line but with the help of Saffron immediately changed the idea that it could be hard to tell the location unless time is known. Mark, on the other hand, was trying to associate the location of events with the intensity of light but Saffron tried to break that association giving the example of the cart activity, and Carol also helped to break it by associating light intensity with energy rather than with location.

Table 6.5: Breaking of Mark's Original Association of Intensity with the Location



I present a segment of interview transcript of another group of students. This group held the 'central tendency' originally, but one of the students came up with different idea, and the group moved to 'non-central'. Two of the students held the idea that intensity of light determines the location. One student was trying to challenge the idea but could not convince his colleagues and eventually this group decided to rely on intensity to locate explosion events in the light activity. Jeffery, Nathan and Matt (all pseudonym and their major have been introduced earlier) are in this group.

> Interviewer: Draw the paths of the explosion bits
>
> Jeffery: It is the center I guess (start from the center of the circle)
>
> Matt: Yes, it starts from the center
>
> Nathan: Not really from the center but kinda of… I don't think from the center I would think that it start from…if it was center it would be zero…

Jeffery: So you are saying that they always break into 180 degrees apart…

Nathan: When they are blowing like towards us and then….

Jeffery: It kinda make sense to me cause it explodes right in the middle of the…equal and opposite…

Ultimately, the group members drew on their worksheet a line joining two lights to represent the paths of explosion bits. After that, they moved to discuss the location of the event along the line. The following is an excerpt of the discussion.

Worksheet question: How to find the location along the line

Jeffery: Can we see that again (after looking the lights)…they are about the same brightness

Nathan: Same brightness…they would be equal distance apart

Matt: Time…yeah…time gonna be the…

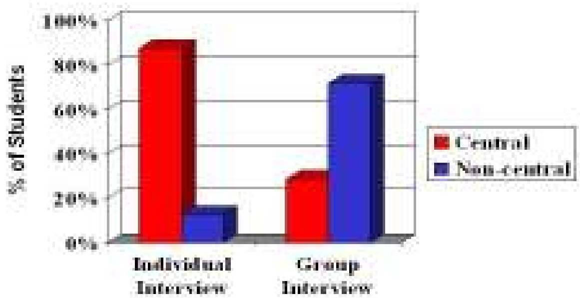
Jeffery: But with…I mean with our eye we can't

Nathan: To locate event …distance…brightness of the light…

The group finally decided to rely on the brightness of the lights and wrote that in their worksheets. The association of location with brightness held by Jeffery and Nathan was stronger than the association of location with time held by Matt. Ultimately, the peers suppressed Matt's association. It is apparent that this group of students did not transfer ideas from the cart activity to the light activity. It could be argued that two of the students (Nathan and Jeffery) in a group had one type of association and the third (Matt) could not disagree too much. But it is clear from the interview transcript that Matt even did not try to put own idea firmly owing to weak association. I speculate that the stronger association like that held by Saffron and Carol in the earlier group would make a big difference even though Matt was the only one having that idea in this group.

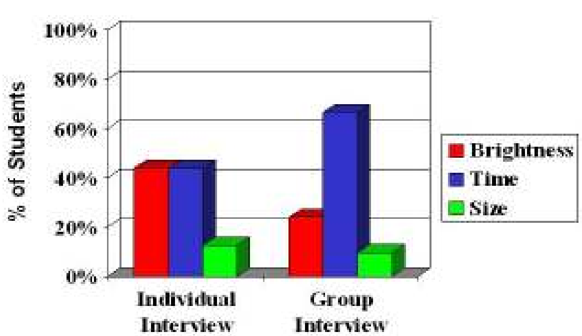
Unlike the individual teaching interviews, a majority of the student groups in the group interviews held the non-central idea. Even if some students of the group originally had the central tendency, their peers easily challenged it. With the completion of their discussion regarding the central or non-central location of the events three groups (6 students) still had the central tendency before I challenged their idea by using the ‘light scaffolding activity’. The remaining six groups (15 students) either did not have any central tendency or changed immediately to non-central with peer interaction. Figure 6.4 shows the statistics of central tendency in the individual and group teaching interviews.

Figure 6.4: Central Tendency in Individual and Group Teaching Interview



The individual teaching interviews used two sequences in introducing the cart and the light activity. The result of event locating factor of the group-teaching interview is consistent with the results of the individual teaching interview. Like the one example presented above, “Saffron: just same thing as cart (cart activity) whichever gets first…that with light I mean…” students referred back to the cart activity to make assumptions to locate explosion event in the light activity. Six out of nine groups (14 out of 21 students) relied on time to predict event location in the light activity. Two groups (5 students) relied on intensity of light and the last one group (2 students) predicted location based on the size of the light spot of the wall of the cylinder. Figure 6.5 gives the comparison on the factors that students of individual and the group interview relied on.

Figure 6.5: Event Location Factors Considered in Individual and Group Interview



In completing the task of event location along the line, student groups took 6 to 21 steps. Students who completed the task successfully had larger step to hint ratios (2-5.25) and had larger qualitative to quantitative reasoning ratios (2-7). The groups that could not get to the target idea had relatively smaller step to hint ratios (1.8-2) and smaller qualitative to quantitative ratios (1-2). The reduction of the external hints could be due to the peer scaffolding. More qualitative assumptions and reasoning were abundant in peer discussion. Students' accomplishment could be because of the peer interaction that facilitated qualitative reasoning before approaching to the quantitative solution of the problem.

6.6.2 Effect of Change in Sequence and Phrasing of Hints

In this section, I discuss change in the students' responses due to the change of the wording and sequencing of questions. At first, I present how the use of the term 'magnetic' changed students' approach in discussing motion of carts in the track. Later, I discuss change in students approach to discuss the number and direction of gamma rays produced by electron-positron annihilation. In both cases, I compare the results of the individual and group interviews.

Motion of the Carts on the Track

Two variations in students associations were noticed when they described the motion of carts on the track. Students described cart motion by either associating cart motion with kinematics or magnetic terms. A relatively larger number of students applied the latter idea in the context of group interview whereas a majority of the students used the former idea in the individual interviews. At first, I describe the student reasoning in context of the group teaching interviews where initial instruction and questions were provided through worksheets.

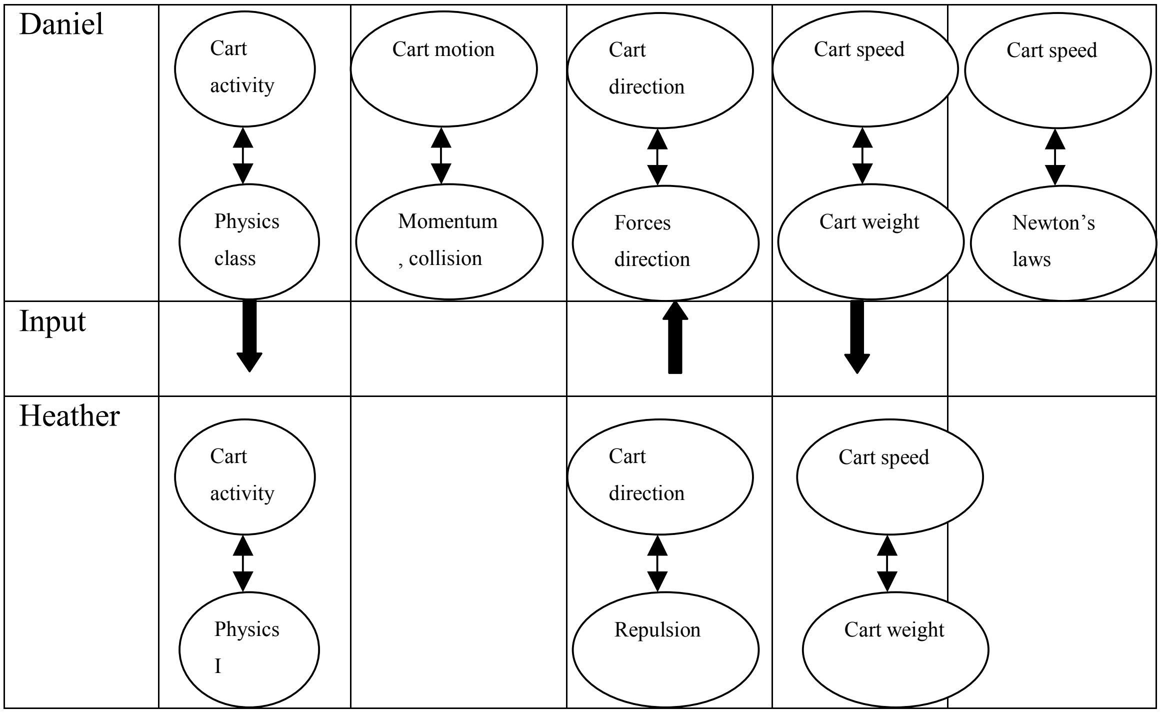
Students were asked to describe the motion of the collision carts on the track. In the worksheet they read the description that the carts were magnetic. Following this, an instruction was phrased like this: 'bring the carts close to each other and release them. What are the carts doing and why?' In response to this question two types of variation in idea progression were noted in different groups of students.

The following is the case of a group of two students. Heather (not real name) is junior in biology enrolled in the first semester of the General Physics course and Daniel (not real name) is sophomore in Statistics enrolled in the second semester of the General Physics course. Both of them had high school physics, and the General Physics was the only physics course they had taken at the college level. The students in this group started out with the association of cart motion with momentum.

> Daniel :(plays with carts)…Ok…ok…I remember this from physics when took that one
>
> Heather: Physics 1
>
> Daniel: Have you done momentum yet…so you recognized this…good…(pause) elastic and inelastic (flips the sides of the carts)
>
> Interviewer: Discuss and write the answer (worksheet question: what are the carts doing and why?)
>
> Heather: They are repelling
>
> Daniel: Like forces…you know…(pause)…their velocities should be equal they weigh the same…
>
> Heather: Yeah…they look like…they weigh same…
>
> Daniel: Newton's second law…basically…is that third law…every action has equal reaction

Table 6.6 shows the student idea progression and associations. A row under student name shows how he/she progressed over several steps. The input row shows if the students got scaffolding from a peer to come up with that idea. The head of the arrow indicates the student who got help from the other student.

Table 6.6: Associations and Progression of Idea: Cart Motion with Kinematics



I present below a different example of association and progression. This group started making association of the cart motion with magnetic property. Ben (not real name) is a sophomore in nutrition science and Teresa (not real name) is a sophomore in biochemistry. Both of them are enrolled in the first semester of the General Physics course and had high school physics. They were provided same set of activities and worksheet questions like other groups of students. The conversation took place as follows.

> Teresa: (play with the carts) They are repelling due to magnetic poles…how to compare speeds…
>
> Ben: I would think the strength of the magnetic field…that will give me…
>
> Interviewer: Are you convinced that strength of magnetic field plays a role here?
>
> Teresa: Yeah…pretty sure
>
> Ben: I would say…we have the…may be…like different magnetic…different magnets (magnetic carts) have different magnetic strengths…I think if it is non-uniform between the two carts…one is pushing more than the other…I don't know it will be like magnetic fields overlap or whatever…I mean if one is

stronger the other it will push with more…it will weigh with…I don't know if it will be…increase the one with pushing…pushing with velocity…

Teresa: The stronger the magnets are more they gonna repel each other and fast they would gonna go…

Interviewer: What measurement do you need to find the carts travel?

Teresa: Measurement of the track…strength of magnetic field

Ben: Probably the mass…

Teresa: May be friction…friction in the track

Table 6.7 Associations and Progression of Idea: Cart Motion with Magnetic Property

Teresa	Cart motion ↔ Poles of magnet	Force of repulsion ↔ Magnetic strength	Distance of cart travel ↔ Magnetic strength, track length	Distance of cart travel ↔ Friction on the track
Input	↓	↑	↓	↑
Ben	Speed of carts ↔ Magnetic strength	Force on the carts ↔ Magnetic field	Distance of cart travel ↔ Mass of carts	

Four out of nine groups (9 students out of 21 students) who participated in the group teaching interview made the association and progression of the first type. They discussed the cart motion using kinematics ideas. The remaining five groups (12 students) made the second type of association and progression.

Unlike the students of the group interviews, 75% of the students (12 out of 16) who participated in the individual teaching interviews made the association of cart motion with the kinematics terms. Only 25% of students (4 out of 16) associated cart motion with magnetism. The students were asked the questions orally. Instead of introducing the carts as magnetic carts, the students were asked if they had seen the carts before and in what context. The conversation began in the following way,

> Interviewer: Where and when did you see this guy first (carts)?
>
> Sara (pseudonym): I mean … I guess in physics lab…not specifically this but we had air track …and we did collision and…there is magnet on it …it's interesting…
>
> Interviewer: I bring them closer and release …what are they doing and why
>
> Sara: They repel each other …I mean… it's a kinetic motion…

The following table presents the student's association and progression of idea when the conversation proceeded further.

Table 6.8: An Individual Students' Association Regarding Cart Motion

Student association and progression	Cart behavior Repulsion	Cart motion Kinetic motion	Cart speed Cart Weight	Distance traveled Time to travel

When I started the individual interviews, magnetism chapters were introduced in the second semester of the General Physics (GP2) class. 3 out of 7 students who were enrolled in GP2 used the term 'magnetic poles' or 'magnetic field' during the individual interviews. This indicates that relatively larger number of students in GP2 used the idea of magnetism.

The group teaching interviews also started when the students enrolled in GP2 were taught the magnetism chapters. Table 6.9 summarizes the students' use of the corresponding ideas during the group interviews. The first column indicates the labeled group numbers. The second column shows whether a student was in GP1 or GP2. The third column indicates the corresponding students' use of magnetic or kinematics terms.

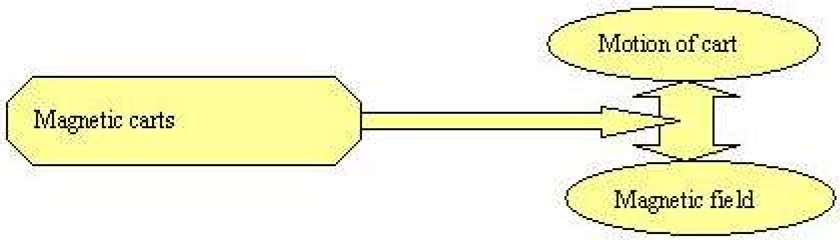
Table 6.9: Use of Magnetism vs. Kinematics in Group Interviews

Group	GP1 (1)/GP2 (2)	Magnetism (M)/ Kinematics (K)
1	2, 1, 1	M, M, M
2	2,1	K, K
3	1, 1	K, K
4	1, 1	M, M
5	1,1	K, K
6	1,1	M, M
7	1, 1, 1	M, M, M
8	2, 1	M, M
9	2, 2, 2	K, K, K

Out of 21 students who participated in the group interviews 6 were enrolled in GP2. 2 out of 6 students considered magnetic interaction and the remaining 4 students used the kinematics terms. This result suggests that there is no strong correlation between using magnetic interaction and being in GP2.

The groups of students who made the association of the cart motion with magnetism were highly influenced by their perception that magnets are involved in the carts so everything should be explained based on magnetic interactions. I speculate that the prior experience of use of carts in laboratory or classroom demonstration was dominant factor in the other groups of students who made association of cart motion with kinematics terms. They brought up the ideas such as momentum conservation, elastic and inelastic collision and Newton's laws of motion once they saw the carts on the track. On the other hand, the use of the term 'magnetic carts' in the worksheet could be the dominant factor in the second group of the students. Once they read that the carts are magnetic, they started looking at two sides of the carts and brought up close to each other and started discussion about the magnetic poles and magnetic field strengths. The students considered the term 'magnetic cart' in the worksheet write up as a strong hint. I did not deliberately use the term as a hint because magnetic interaction was not the target idea in this context. But, students using it as a hint, made further magnetic interaction assumptions to describe the carts' motion.

Figure 6.6: Influence of Magnetic Idea on Motion of Carts



Based on the statistics of the result, it seems that more students are influenced by the strong hint than their prior experience from physics class. Along the line of the two-level framework of association, it could be argued that, for the hints to be influential, students must have the resources related to the strong hint from prior experience. In the above discussion, the term ‘magnetic cart’ could activate students’ resource of magnetism just because they had experience about magnetism from everyday life or high school physics. If they never had such experience, then the term ‘magnetic cart’ as external input could not even pass through the sensory filter to serve as the strong hint.

The sequence of the information and questions presented in individual interview was as follows: i) Where and when did you see the carts before? ii) I bring the carts closer and release. What are they doing and why? On the other hand, in the group interviews, the sequence was as follows: i) In this activity you are using two magnetic collision carts. At first play with these and get some idea on how they behave ii) Bring the carts closer and release. What are they doing and why?

The reason of inclusion of the first part was to familiarize students with the carts before asking them an actual question. The second part, which was the actual question, was phrased in similar way in both the cases. Based on the result of the study, I speculate that the background information provided to the students in two different ways has a lot to do with the activation of the different conceptual resources of students. Asking them ‘where and when they saw the carts’ activated their prior experience of physics class where they used the carts in collision and momentum conservation experiments. In response to the subsequent question, students associated the target tool ‘cart motion’ with the activated source tool such as ‘momentum conservation’ from kinematics domain. This association was so strong that it suppressed the association of ‘cart motion’ with ‘magnetism’.

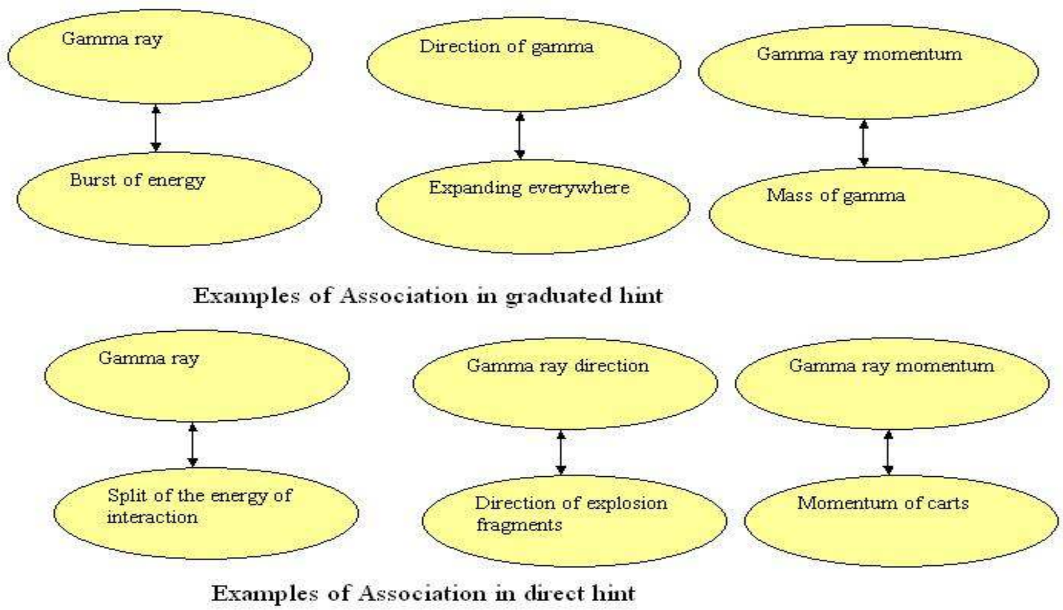
On the other hand, students activated prior resources related to magnetism when the carts were referred to as 'magnetic carts'. The source tool such as 'magnetic field' or 'magnetic poles' was activated from the magnetism domain and that was associated with the target tool 'cart motion'. This association suppressed their resources experienced from prior classes. Since the two domains were so distinct, students making the two different types of association diverged significantly unless interviewer and peer scaffolding came into action. This result indicates that the hint or background information provided before the actual question highly influences the students' response in the actual question. This shows the necessity of careful phrasing and introduction of information before asking any questions to students.

Momentum Conservation in Annihilation

Both in individual and group teaching interviews, students were asked to describe the least number and the direction of gamma rays produced in the electron-positron annihilation process. I reiterate the numerical result of students' responses in individual interviews to compare with that of the group interviews. None of the students applied the idea of momentum conservation themselves in the individual interview even though the phrase 'momentum of system is zero' was provided as an indirect hint. 11 students started out with one as the least number of gamma rays and two students considered zero with the same reasoning that it is the smallest possible number. Another two students who started out with two as the least number did even not use the idea of momentum conservation. They associated the number of gamma rays with the number of interacting particles rather than associating the number with momentum conservation.

The sequence of presenting the question and hints in the context of individual teaching interviews was as follows. They were first given the instruction that mass of electron-positron changes into gamma rays energy and also informed that electron and positron system has zero momentum when they approach. They were then asked about the least number of gamma rays produced by the process. Once none of them could give the correct answer, they were directly told to apply the momentum conservation principle in the process. Only five of them (33%) were able to come up with the correct answer and the correct reasoning. Whereas the remaining 10 students (67%) needed strong hint such as "…momentum was zero before and to have zero after how many gamma rays in the least should be produced" or even stronger hints such as " can you have zero momentum with a single gamma ray traveling?" to help them come up with the target idea.

Figure 6.7: Students' Association About Gamma ray



Students in the group interviews were provided with the direct hint at the beginning. The question in the worksheet was phrased like the following: " when an electron and positron annihilate how many gamma rays in the least should be produced in order to conserve the momentum (hint: momentum of the electron-positron system was zero just before annihilation)". The result was that 15 out of 21 students (72%) of different groups individually came up with the idea immediately and wrote that there must be at least two gamma rays produced in the process to conserve momentum. However, three out of nine groups explicitly used the 'two in and two out model of collision' that is described in Chapter 5. A student of a group based her answer to the activity in the first session even though it was not relevant at this context.

> Carol: Like in the last time (first session)…when they annihilate it split up into two directions…they scatter…the movement will be equal and opposite…so that the momentum stays zero…so I think at least two…

A student of another group made the following statements to explain his answer, which is influenced by the 'two in two out model'.

> Jeffery: That might be two…I was just thinking because conserving momentum you hit and may be two…like they are coming in and …electron and positron coming this way…cause it is two…so gamma…(pause)

It was a coincidence that in each group at least one student came up with the correct answer and then he/she scaffolded others to come up with correct answers. So, at the end all the groups reached to the consensus that two should be the least number of gamma rays produced by electron-positron annihilation.

It is reasonable to compare the performance of the students only at the stage when they got a similar hint. Students of the individual interviews originally got the indirect hint (momentum of system was zero) but no one could state the correct answer. After getting the direct hint (need to conserve the momentum) 33% of them got the correct answer. On the other hand, 72% of the students who participated in the group interviews could state the answer successfully after they got the direct hint.

I speculate that the students of individual interviews were engaged in a process to think about gamma rays features before they received the direct hint and majority of them failed to associate the gamma ray motion with momentum even after getting the direct hint. On the other hand, students of the group interviews got the direct hint right away and did not have much time to make a complicated gamma ray picture in their mind. They immediately applied the momentum conservation principle even without knowing much about gamma ray itself.

In view of constructivist learning philosophy, students should be provided with an environment where they can make the hypothesis and test it themselves. Consistent with this a number of graduated weak and indirect hints can provide the suitable learning situation. This provides students an ample opportunity to construct ideas before jumping to the answers. The results of this study showed that students' performance was better when they were provided the direct hint instead of graduated hints. However, it is found that the students gave the right answer with wrong reasoning when the direct hint was provided and they gave wrong answer with relatively better reasoning when the hints were graduated. Some instructors might be interested to help students learn some of the useful facts and some may want to cover every aspect of a concept. The above result suggests that former type of instructors need to use the direct hints and the later ones should use the graduated indirect hints.

6.6.3 Group Interaction in Transferring Learning

In Chapter 5, I presented different types of transfer of physics learning in the context of individual teaching interviews. In the context of group interviews two aspects of transfer of learning were investigated. First, I investigated if there was the statistical change in the types of transfer and the second in what way peer interaction played a role in the transfer.

The classification of the different types of transfer is based on criteria similar to that discussed in Chapter 5. A student group is said to make spontaneous transfer if they correctly answer the PET problems and refer to the physical models immediately during their explanation. If they refer back the physical models upon being asked the basis of their answer, this group of students are considered to make semi-spontaneous transfer. If the students groups are successful in solving the PET problem but make the association of the physical models with the PET problems only after being asked if they saw a similar situation before, the students are said to be in non-spontaneous transfer class. The students groups are said to be in no transfer class if they are not successful in their task of the PET problem.

The definition of type of transfer in the individual and in the groups can be somewhat different. It could also be argued that a student in a group might be in a spontaneous class and one student could not even transfer if the latter had participated individually. When I state that a group transferred spontaneously, I mean that every student contributed in problem solving and made associations with the physical models. If one student started out the discussion and other students helped to build upon each other's idea, then I considered that the group as a whole transferred. On the other hand, if a student in a group could solve the problem successfully and the other students of the group seek clarification to make sense of it, then I put the latter ones in either the low level of transfer or no transfer class.

Based on the students' statements and type of conversation during the group interaction, I noticed either spontaneous, semi-spontaneous and no transfer in this study. The following example shows how a group as a whole transferred spontaneously. Emma is a pre-med senior student and Olivia (both pseudonyms) is Junior in pre-vet medicine.

> Worksheet question: Consider only one annihilation and refer to the above diagram (diagram provided in the worksheet) to describe the process to determine the exact location of annihilation.
>
> Emma: It will be like the circle in the first …

Olivia: The lights

Emma: Yeah…it would be like that because you don't know where inside the circle it is…like the skull…

Olivia: Where the annihilation occur…but we see in the edge

Emma: Yeah…like it…I would follow linear so…where it bounces back would be…

The following transcript segment of a group of students (Carol, Mark, and Saffron) gives idea how students in the same group transferred differently.

Questions: You have just one event in this picture describe the process of determination of annihilation location

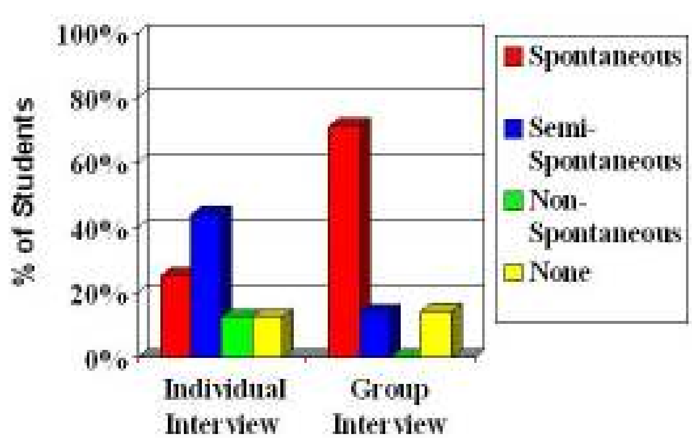
Mark: It is same thing like the cart…because we can't see it and the time it took for one cart to hit was different than the other…so may be it's difference between the time…I don't know if we can detect that or not…

Carol: It (coincidence circuit) knows the time difference …this side and this side…

Saffron: Cause I don't know…is everything should be as he (Mark) said possible…that's my guess

Mark definitely transferred spontaneously, Carol transferred after getting scaffolding from Mark and Saffron did not transfer at all.

Figure 6.8: Comparative Study of Types of Transfer



While counting the number of students exhibiting different types of transfer I even separated students of a group in different classes based on their responses in the group interaction. If two of the students in a group transfer spontaneously I put the third student in no transfer if the student had a hard time to make sense of the peers' discussion.

The statistics presented in the Figure 6.8 indicates that the largest student population falls in spontaneous class and semi-spontaneous comes second. This is opposite to what was reported in the individual interviews. As discussed in Chapter 5 (Section 5.6.3) there is not much difference in spontaneous and semi-spontaneous transfer in terms of student learning. It could be the possibility that some students immediately express their association of the physical models with the PET problems and some do not want to even though they make the similar association internally. The exhibition of spontaneous transfer by a larger student population in the group interviews showed that students more openly express their internal associations with their peers.

Students in the groups helped each other in triggering their association of the physical models with the PET problem. Emma and Olivia were helping each other to make association in one example presented earlier and Mark and Carol in the other. This association, which is considered as transfer of learning in this research, is facilitated through peer interaction. The total percentage of spontaneous and semi-spontaneous in the individual interviews was almost 74% whereas that in the group interviews was 85%. This indicates that group interactions have enhanced the transfer of physics learning from the physical models to the PET problems.

6.6.4 Effect of Group Size in Learning

Students worked in the groups of two or three. The purpose of dividing students in two different sized groups was to see the variation in the group dynamics in the different settings. There were three groups of three and six groups of two students. Originally, I intended to make equal number of groups of two and groups of three but this did not happen because of the absence of some students. Because of the small sample of groups, I do not claim any generalization from the results, and I do not provide many numerical comparisons. The description just presents the process of learning observed in the different sized groups.

As an example, a progression diagram of a group of three students is presented in Table 6.10. The students took altogether 12 steps in completing the 'annihilation-locating task'. However, I present below eight key steps. Out of 12 steps, Jeffery was involved in seven steps, Nathan in 4 steps, and Matt in just one. This indicates that there was unequal participation of the students in the group. It is definite that Matt had significantly low participation. This situation was common in all kind of tasks within a group and in all of the three person groups. Typically two of the students were engaged in the conversation for their idea progression and the third one just observed the discussion and expressed agreement or disagreement. Table 6.10 shows how the student who did not participate much ultimately was able to change the idea of all.

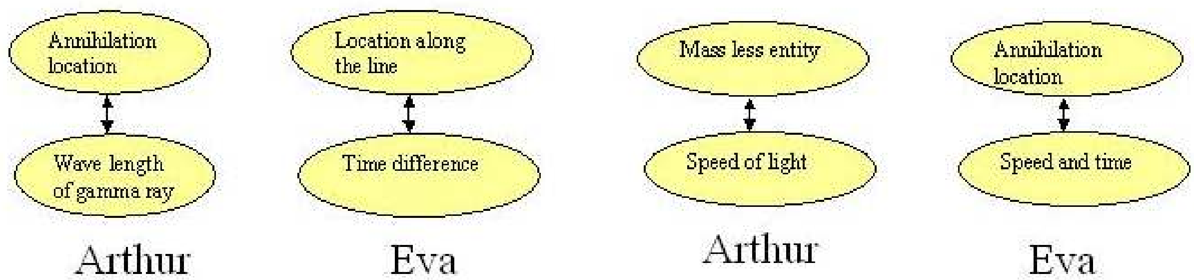
Table 6.10: Group Dynamics in a Group of Three Students

Associations	Annihilation locating $\leftrightarrow$ Light activity	Closer $\leftrightarrow$ Stronger	Location $\leftrightarrow$ Intensity	Location $\leftrightarrow$ Time
Students Steps	Jeffery 1 (question asked)	Nathan 2	Jeffery 3	Jeffery 4 (hint given)
Associations	Location $\leftrightarrow$ Intensity	Locating event $\leftrightarrow$ Cart activity	Location $\leftrightarrow$ d=vt	Location $\leftrightarrow$ Speed, time difference
Students Steps	Nathan 5	Matt 6	Jeffery 7	Nathan 8

Up to the third step they associated ‘location’ with ‘intensity’ with the help of the light activity. This group of students had used the idea of intensity in the first session. At the fourth step a hint was provided to facilitate an alternative association. They were asked if they were not certain about intensity, what would they rely on. Jeffery was able to associate ‘location’ with ‘time’ after getting the hint but Nathan still could not. Matt was not active in conversation up to this point, but he suddenly associated locating annihilation with the cart activity. This association influenced Nathan and Jeffery. All of them not only associated the ‘location’ with ‘time’ but also were able to do the task quantitatively.

Below is a typical example of group interaction in a group of two students. Arthur and Eva (both pseudonyms, Arthur is junior in chemistry and Eva is sophomore in pre-veterinary medicine) were engaged in seven steps altogether in completing this task. Arthur was active in four steps and Eva in three. I present the four important steps of progression in Figure 6.9.

Figure 6.9: Progression in a Group of Two



The dynamics of the group interaction shows that both the students participated equally. Originally their ideas were diverging. Arthur had focused more on wave aspects of gamma rays, and Eva concentrated on a mechanistic view in the annihilation process. Eva associated annihilation location with time difference and speed without having any knowledge about the speed of gamma rays. Arthur said that gamma rays do not have mass and therefore travel with the speed of light. Finally their ideas converged, and they agreed that the speed of light and difference of time for the gamma rays to reach the detectors of machine is used to figure out where the gamma rays started.

In the groups of three students, two students always led the discussions and the third students provided useful input at different stages of the conversation. The third students put forward his/her own ideas only when he/she disagreed with the outcome of the first two students' conversation or when he/she needed further clarification. In several instances the third student succeeded in changing others' ideas. The possibility of change of others' ideas was dependent on the strength of association made by the third student rather than how close he/she was to the target ideas. The average time taken by groups of three students was 30% more than that taken by groups of two students. This is reasonable because the students brought up the greater number of ideas in the group of three. The interviewer was relatively more active in groups of two students in challenging their ideas at several stages of the interview. The third student who was monitoring the other two students' discussion in the groups of three challenged others' ideas at several stages. So, the role of the third student of the groups of three students was similar to the interviewer in the groups of two students in several stages of the teaching interviews.

Based on this research, I cannot claim the superiority of students' learning in one group size versus the other. I just presented the situation in terms of the time taken to complete the task, the types of interaction and the interviewer's role in two different group sizes. However, I noticed that students of group of three needed fewer hints from the interviewer. In the four major categories tabulated, the average steps to hint ratio was 2.78 for the groups of three and 1.93 for the groups of two (please refer the Appendix N), they were more interactive and they were more successful in the group tasks but they took 30% longer to complete the tasks in comparison to the groups of two students. It could therefore be argued that when students work independently without instructor, group of 3 are likely to be more effective.

6.7 Chapter Summary

In this chapter, I presented the group teaching interview method to investigate students' learning and learning transfer. The purpose of using the method was to investigate the dynamics of students' knowledge construction and reconstruction in the context of group interaction. Group teaching interviews were conducted using the physical models to investigate the role of peer scaffolding to reorganize students' physics knowledge relevant to PET. To make the interview setting a mock classroom situation students were provided with the worksheets to work on individually and then discuss with their peers. A phenomenographic approach was used to analyze the data. The variations in students' associations and progression in the different stages of the teaching interview was established.

The findings of the research were divided into three major sections. In the first section I discussed the role of peer scaffolding in problem solving. The results showed that the students' idea progressed significantly to more scientific when they worked in groups. The students helped each other not only by challenging peer's ideas but also by providing them resources to make the alternative reasoning. The study could be explained in terms of ZPD (Vygotsky, 1978) at different stages of the teaching interviews. A large majority of the students could accomplish only up to a certain level of tasks in different stages of the teaching interview by themselves.

Their accomplishments were enhanced significantly when the interviewer provided them scaffolding and were enhanced even further when they worked in groups.

In another section, I discussed the change in students' responses with the change of sequence of hints or information. I reported two stets of results to describe the hint sequencing effect. The first one was in context of students' explanation of motion of collision carts. Students were asked to describe the motion of 'carts on the track'. Before asking this question, some students (who participated in the group interviews) got the background information that the carts were magnetic, and the others (who participated in the individual interviews) were asked if they had prior experience about the 'carts on the track'. Most of the students who got the information of 'magnetic carts' used the idea of magnetism to explain the cart motion and the carts travel. On the other hand, a majority of the next group of the students used the kinematics idea to describe the motion. I used two level theoretical framework introduced in Chapter 3 to explain the results. The result on sequencing of weak hints and strong hints in context of electron-positron annihilation was also discussed. Students who got the strong hint before the weak hint performed better to come up with the target idea. Many of the students who got the hints in opposite manner could not get the target idea easily. However, the former groups of students could not construct a clear picture about gamma rays as compared to the later group of students.

In yet another section, I discussed peer scaffolding in transferring physics learning to understand PET. The results of this study indicated that the students helped each other to facilitate transfer of physics learning from the physical models to the PET problems. The students could trigger each other's ideas to associate the physical models with the related PET problems.

In the final section of results and discussion, I compared the types of interaction in group of two and group of three students. The purpose was to investigate if one group size was better than the other in student learning. The result indicated that groups of three were more interactive and the interviewer's participation was minimized. Students intended to comment on each other's ideas rather than ask to the interviewer to know the target ideas.

CHAPTER 7 - Conclusions and Implications

7.1 Overview of the Study

This study was carried out in the context of development of research-based teaching activities to help introductory level physics students learn physics of PET technology. Students in the introductory level physics classes learn physics without knowing much about the physics application in other fields. The research effort contributes to the physics teaching and learning areas in mainly two ways. First, the physics problems discussed are useful to motivate students in learning physics. Students after discovering that physics is applied in everyday life and fields such as medical technology can be motivated to learn physics. Second, the transfer of physics ideas in different contexts helps students consolidate their physics learning.

The physics ideas involved in PET range from simple kinematics to modern physics concepts such as the mass-energy relation. This study used interactive instructional strategies to help students construct the modern physics knowledge from their prior physics ideas. A learning cycle methodology (Karplus, 1977) was used to develop teaching activities, which covered various physics concepts involved in PET. The teaching activities used hands-on activities so that students learned a wide range of physics concepts without requiring high cognitive load.

A teaching interview methodology using the hands-on activities was used to investigate student learning of image construction process of PET. The main aim of the research was to explore the strategies to help students understand and apply the range of physics ideas. The first step along this line was to investigate students' prior ideas and conceptual resources. The research used scaffolding activities to help students change and develop their prior ideas. The strategies of anchoring conceptions and bridging analogies (Minstrell, 1982) were used when students already held scientifically accepted ideas. At some stages of the teaching interview, their incorrect ideas were challenged by either cognitive dissonance or disequilibria method. The goal of those strategies was to help them construct and reconstruct their knowledge.

The participants of this study were mainly students enrolled in an algebra-based introductory level physics course (GPI and GPII). In all, 37 students were interviewed and more than 73 hours of interview transcripts and video served as the main data source. The physics education researchers at KSU and upper level undergraduate students participated at the early stage of the research. The individual interviews of 16 GPI and GPII students were conducted to investigate the students' prior ideas and transfer of learning using the physical models. Each student was interviewed twice at a spacing of about one week. In the next stage of the research 21 students were interviewed in groups of two or three to explore students learning and the transfer of learning. I focused on the dynamics of knowledge construction in the social context.

This research used a qualitative research method. Colaizzi's (Cohen & Manion, 1994) procedure was adapted to analyze the qualitative interview data. A phenomenographic approach (Marton, 1986) was used to establish the variation in different categories coming out from the interview transcripts. A resource based theoretical framework based on the cognitive perspective of learning and consistent with various contemporary views on transfer of learning was employed to investigate occurrence of transfer. The peer debriefing was employed to check the credibility of qualitative data analysis process.

7.2 Teaching Activities and Students' Reflections

Hands-on optical and mechanical activities were used to scaffold students' physics ideas in this research. The activities resembled some portions of the working of PET technology. Students were expected to learn physics ideas by concrete experiences with the analogy activities and later apply in the related PET ideas. The activities referred to as the physical models in this research were expected to convey the abstract physics concepts in learning and transfer of learning.

I describe below the participating students' perception about the activities and their physics learning using the activities. I have mentioned earlier that the type of problems used in the research motivates students learning of physics. As an example, I present a student's remark after doing the activities and realizing that her physics learning is meaningful for her future career.

> "So this (the activities) shows that you can actually use… used right now in fields like better out side of just physics …just like specifically medical field …that I wouldn't really think of physics being involved …so may be like in my job I have to be using these physics too…"

Earlier I had argued that students learn and understand physics better if they are engaged in application or transfer problems. Students explicitly mentioned that the application of physics to other fields helped them a lot to understand the physics concepts. The following statement is an example along the line.

> "The activities helped to understand physics ideas… being able to relate to more like common examples like PET…like more everyday kind of situations how…versus…like it is being able to just like believe the concepts and then knowing that it happens… still is rather abstract idea but then it's actually being able to…here is the situation and it takes place and how it works makes me able to …ok, that makes sense… now I understand why it is being said or why it works… thus by using in the outside fields…"

There was one instance when a student mentioned that her learning preference is trial and error method. She admired the activities because she could interact with the physical models to test her prior ideas and changed them whenever she was wrong. In her words,

> "I think specially … I learn best from trial and error thing… I learn… when we were doing the carts and then you ask about the difference in time, velocity and stuff …what I make a mistake and I think I am right and then… oh this is the way to do it …"

Her statement of trial and error method is consistent with cognitive dissonance method discussed by cognitive psychologists. Students predict some outcome in the activities based on their prior ideas, and they test it. When they do not get the expected outcome, they change their idea and test it again until their newly constructed idea and the outcome of the result from the activities match.

There were several instances where students self reported that they learn physics ideas better because of the interactive nature of the activities.

> "Sometime kind of difficult seeing in your head or whatever…whereas as you actually see objects moving you can really kinda get the better feel for it…very…you know like with the differences in time and thing very easy to actually see that first hand and apply that…and then the activity with the lights around the circle you know just the process using momentum or you know …travel opposite direction to one another things like that…kinda really do that hands on …"

A student reported that her learning style is visual. The activities provided her ample opportunity to learn visually. This indicates that the activities meet the need of the visual learners.

> "I learned visually so I learn better when I see what's been described rather than talking about gamma ray …you can't see it …you can't touch it ….so being able to see and visualize what's going on this makes me easier to understand"

The teaching activities provided students a constructivist-learning environment. They were engaged to learn by constructing their knowledge at several stages of the teaching interview. For example,

> "I was here for a long time and I was thinking and you just challenged my ideas with the light bulbs…how do you know that…why…and made me think critically and made me really think like why is this happening and so… I think that was the basis of all these learning …"

Students were excited about the activities used in the teaching interviews. They compared the interview activities with the classroom activities and said that their classroom activities were more theoretical whereas they learn more from more concrete experiences like those used in the teaching interviews.

> "I guess I would learn more from activities like this (activities used in the teaching interview) than from the activities that we are doing now in our classes …I definitely like stuff like this, which is more conceptual, and it is not so theoretical…"

The physical models served as analogies and were useful to facilitate transfer of ideas from a familiar concept to an unfamiliar one. This is consistent with Glynn's (1998) remarks that analogies can help to build meaningful relations between what students already know and what they are setting out to learn. For example,

> "Last time we were dealing with collision and see how to figure out the…how to determine where it is happening and really that's the same thing happening here (refers the PET coincidence picture)…cause we can't see somebody's brain and determine how much activity that organ is doing so we applied …used injection to see the amount of annihilations to determine where it is…"

Using the activities the students were successful in transferring the abstract physics ideas. The following example shows that they saw the common features in the physical model and the PET problems.

> "The box that we worked with last time probably was the most helpful …and then it was like scale model of the tomographer ...have we not done the box …the circle box last time…. I really wouldn't have gotten what was going on here (PET

> scanner) ….it helped me to get the mental picture of how conservation of momentum really works"

The discussion above provides significant information to make a reasonable argument that the activities were successful in helping students learn physics in many aspects. They were particularly helpful in student motivation, cognitive dissonance, and knowledge construction. In addition, the activities could meet the need of visual learners and those who could learn only from the concrete experiences. The students' statements indicated that the activities served as analogies which helped transfer their physics learning to the contexts of medical technology. It is even more encouraging that students transferred abstract physics ideas using the activities. However, there was some evidence that students transferred negatively (for example; two carts therefore two gamma rays).

7.3 Results of the Study and Their Implication to Instruction

In this section, I reiterate some of the results of individual and the group teaching interviews presented in Chapter 5 and 6 respectively and discuss their implications in physics instruction. Based on the results discussed in Chapter 5, I focus on how to choose hands-on activities and their sequencing. The results discussed in Chapter 6 are extended to suggest the need for encouragement of group learning in classroom and the sequencing of hints.

Identification and Challenging Inappropriate Ideas

There was evidence that students used symmetry arguments in inappropriate situations. Central tendency was the most influential symmetry reasoning held by more than 80% of the students. The students' 'circular central tendency', the belief that if more than one object comes out from a circle their common origin is the center of the circle, originated either from their intuition or from prior physics learning. The 'linear central tendency' forced them to think that if two objects come out after an explosion of a body, the bits must start from the center of the line joining the points where the bits appear. They held this idea by their automatic thought process that the explosion always starts from the center of the exploding body, the explosions bits are of equal mass, and the energy shared by each explosion bits is of an equal amount.

The research showed that the 'central tendency' is very popular among the students but it is weakly held. It could be challenged either by asking them for the reason for their answer or by providing some scaffolding. It could therefore be argued that the symmetry arguments are not as serious as preconceptions or alternative conceptions. However, the results of this research indicated that the symmetry reasoning hindered students' learning.

The identification of this kind of student reasoning is very important before an instructor presents a new idea to his/her students. Teaching a new concept without challenging such ideas leads students in an undesirable direction. There were some instances in the teaching interviews where I used the method of cognitive dissonance and was able to help them modify their symmetry arguments. The 'light scaffolding' activity is one of the examples which was very useful to help students realize that two explosion bits can start off center and move in opposite directions. This result suggests the physics instructors need to identify students' inappropriate reasoning and then design questions or scaffolding activities to address them.

Activation of Appropriate Students Resources

The cart activity and the light activity were introduced in two sequences to the students who participated in the individual teaching interviews. Eleven students were engaged with the light activity before the cart activity. A majority of them (7 out of 11) predicted the location of an event in the light activity by relating the location of an event with the intensity of lights. Another 5 students interacted with the cart activity before the light activity. All of them (5 out of 5) explained the process of event location by associating time with the event location in the light activity. None of the ideas was wrong. However, I wanted the students to make association of 'location' with 'time' in the context of the light activity because it is more relevant when nothing about the source of light is known. The result indicates that students' appropriate association was enhanced with the sequencing of the cart activity before the light activity.

The light activity was effective in helping students learn about momentum conservation, prediction of location and determination of annihilation spot in PET technology when the cart activity was used before the light activity. The result provides physics instructors idea that students have a wide range of reasoning resources. A hands-on instruction may not trigger the students' appropriate reasoning for shaping explorations. Students' inquiry builds on their own prior reasoning that they see relevant in a context. The hands-on instruction becomes effective only when it can create a context to facilitate activation of students' appropriate reasoning. The result suggests that the instructors need to plan hands-on activities (if there is more than one) in an order such that a relevant student idea is triggered and irrelevant ideas suppressed. The physics instructors should realize that the effectiveness of hands-on activities can be related to the sequence in which they are introduced.

Choice of Mode of Representation

Almost 70% of the students who participated in the individual teaching interview self reported that the cart activity was more physical and the light activity was more abstract. It is interesting to note that in both cases the events were hidden and they could see the end results only. One difference was that one of the activities used a mechanical and the other used an optical mode. The other difference was that unlike the light activity the students had seen related cart behavior several times in their prior physics classes. So the students were more comfortable with the cart activity than the light activity. Students on the other hand were engaged in critical thinking while interacting with the light activity and that enabled them to understand momentum conservation principle and eventually image construction process in PET.

The result indicates that students should be provided with the physical models that are concrete to help them build their confidence and then use more abstract models to help them understand abstract ideas. This idea is in the line of constructivist theory of learning where students are helped to construct new ideas building on their prior knowledge. The sequencing of the cart activity before the light activity is justified from this perspective also.

Learning Enhancement through Group Interaction

In Chapter 6, I presented various evidence that the students' learning was significantly better through group interaction. Peers were capable of challenging each other's inappropriate reasoning such as the symmetry arguments. They were able to break the inappropriate associations such as 'location' with 'intensity'. The quantitative problem solving such as figuring out the quantitative location of the hidden event was improved significantly when they worked in the groups. I explained the results using the framework of Vygotsky's (1978) zone of proximal development. As concrete examples, some results were discussed presenting what students could do without any help, with scaffolding from the interviewer, and with the help of more capable peers. Their progression of ideas was possible by building upon each other's ideas. The peers were effective instructors because they could share a common understanding through common language. Language in this context does not mean the spoken language but the language through which they understand physical phenomena or situations. I also discussed the difference in dynamics of learning in 3-person groups and 2-person groups. It was found that the 3-person group was more effective in group interaction and learning even though the groups took relatively longer to complete the tasks.

Two recommendations are provided to the physics teachers based on the finding of the study in group learning. The result indicates that it is important to encourage group interaction in the classroom. The teachers can provide a secure situation through peer interaction to promote students epistemological belief that physics knowledge not only comes from authority but also by free creation and fabrication. This result does not intend to mean that teachers should set themselves completely aside from student learning process, but it means that a successful teacher prefers using the students' physics language rather than a physicist's language.

Transfer of Learning through Interactive Engagement

Students interacted with the physical models in the first session and engaged with the physics problems related to technology of PET in the second session. The results of the research showed that students transferred their physics learning from the physical models to the PET problems. The occurrence of transfer of learning reported by this research is classified into three types. Transfer of learning enhanced when students were engaged in the group learning settings. The transfer assessment was done using the contemporary view of association of resources.

The occurrence of the transfer reported by this research contradicts many of the traditional works on transfer (Chen & Daehler, 1989; Chen *et al.*, 1995; Gick, 1980). The difference in the results between the earlier studies and this research could be attributed mainly to the transfer assessment method and the students' engagement in the learning process. Many of the traditional methods assess transfer by pre-determining what need to be transferred whereas this research uses a framework that considers whatever is transferred. The traditional methods view transfer of learning as the students' specific approach of problem solving. This research regarded transfer of learning as the association between students' prior learning and read out information of a new context.

Most of the prior studies in transfer of learning used the traditional methods of instruction in the learning stage. Students were either given a reading sheet or they heard a lecture in the learning stage. Moreover, students who participated in the prior studies worked individually in both the learning and the transfer stage.

I mentioned earlier that the occurrence of significant transfer in this study could also be credited to the students' engagement in the learning sessions. I explain below mainly two different ways in which it might be possible. First, students activated various conceptual resources during the learning stage. This study used interactive activities in the learning stage where students actively learned using hands-on activities. The activities were useful in challenging their prior ideas at several learning stages. Such activities were useful in activation of appropriate conceptual resources and suppression of inappropriate ones. Moreover, several scaffolding activities were used to help students bring up more advanced reasoning resources. Activation of resources by using active learning might have strong impact in substantial learning. Such activations during the learning stage could be useful in the facilitation of associations of resources in the transfer stage.

Second, their learning was substantial through the construction and co-construction of knowledge. This study provided students social contexts while learning with the help of an instructor or the peers. Students got opportunity to learn in their Zone of Proximal Development (ZPD) during the learning stage while interacting with the interviewer (instructor) and peers. Student learning was improved significantly when they worked with more knowledgeable others. Their enhancement of learning achievements might be a factor responsible to promote transfer of learning. Students were found effective in breaking of peers' inappropriate associations and mending of the appropriate ones. Due to students' self-construction of knowledge and active engagement in breaking and associating resources during learning stage, they could produce stronger but easier associations of conceptual resources in the transfer stage.

The research finding in the transfer of learning has implication in physics instruction. Most of the traditional physics instruction engages students only in the problem solving contexts. Based on the results of this study, it can be argued that to facilitate students' transfer of learning the teachers need to engage their students actively not only in the problem solving tasks, but also in the learning stage. The findings therefore back the non-traditional instructional strategies where students are active in the different stages of teaching learning activities. The results of the research also recommend that physics instructors encourage the group interaction to promote transfer of learning.

Hints and Information Sequencing

This research showed that the sequencing of hints and information can have significant influence in students' responses. Most of the students of the group who got strong direct hints followed by weak hints got the correct target idea. For example, the students were directly told to apply momentum conservation to predict the number and direction of gamma rays in the electron-positron annihilation. They stated immediately the correct answer without knowing detailed knowledge of gamma rays. The majority of the students of the group who got the weak hints and then the strong direct hint did not get the target idea as easily.

In another experiment, students were engaged with two different types of conversation before being asked the same questions. A group of students were told that the carts used in the cart activity were magnetic and another group of students were requested to tell about their prior experiences using the carts. The group getting the information that the carts were magnetic associated the cart motion with magnetism before getting the scaffolding from the interviewer. The other group described cart motion by using kinematics ideas right from the beginning.

Usually much attention is given to phrasing questions to help students learn and to assess student learning. The above results suggest that it is important to pay equal attention while providing background information. This result also suggests that instructors should be very careful while providing hints. Graduated weak hints can be provided to help students engage in constructing ideas. Strong direct hints take students to a desired target idea much faster but without engaging them to construct knowledge. So, using very strong hints sometimes could be no different than lecturing students. Thus, the strength of hints should be such that students get opportunity to learn and transfer their learning through constructing their ideas.

7.4 PET Learning Materials

The main goal of this research was to create teaching materials to help students learn physics ideas and apply those to understand PET. The first step of the effort presented in this dissertation was the creation of teaching materials on various physics topics used to describe PET technology. Some of the teaching units were discussed in Chapter 4. As described in Chapter 4, the learning cycle format was used to develop the activities. Teaching units began with the students' exploration by using interactive activities followed by the concept introduction. Finally, students were given problems where they are supposed to apply what they learned in the first two stages of the learning cycle. The PET related problems were presented in the application stage of the learning cycle of each of the units. I primarily focused on the development of the activities on coincidence detection, radioactivity, mass-energy relation, electron-positron annihilation and photoelectric effect.

The major focus of this research was the coincidence detection and image construction process. However, electron-positron annihilation was another key idea introduced in the teaching interviews. Thus, I discuss the teaching unit which is developed based on the worksheets used in the teaching interviews. After the completion of the unit, I expect that students will be able to locate the hidden events quantitatively, identify the variables useful to find the location and use the variables to get the numerical results wherever possible. Another instructional goal is that students will be able to do statistical reasoning to locate a large number of events when individual locations cannot be ascertained. As another goal, students are expected to apply the momentum conservation principle in electron-positron annihilation in predicting direction and number of gamma rays produced in the process. Moreover, I expect that students will be able to apply the ideas of kinematics and momentum conservation principle in ascertaining annihilation location used in the PET technology and apply the statistical ideas to explain image reconstruction method in PET.

Various results of the research provided useful ideas to design the instructional format and the instructional unit. The activities will be used in a laboratory-like setting where students work in groups. For the detailed draft please see Appendix S.

The teaching activities start with the exploration. Students start their exploration with the cart activity to understand the process of locating hidden events in 1-dimension. Students then switch to the light activity where they explore the pattern of multiple events in 2-dimensions. The distance-time equation and momentum conservation are discussed during the concept introduction stage. The scaffolding activities such as the 'light scaffolding activity' is used to challenge students' ideas if they had problems such as central tendency and circular geometry, direction of bits, and are not able to use momentum conservation. The concept application stage begins with a brief introduction of PET as a medical technology. They are provided information such as injection of positron-emitting tracers to a patient, emission of positron by atom, and change of mass of electron-positron into gamma radiation. A series of PET problems are then introduced. At first, they are asked to predict the number and direction of gamma rays in light of momentum conservation. A model or picture that shows the detector configuration of PET scanner (similar to what had been used in the teaching interviews) is then presented and students are asked to draw and explain the process of locating individual annihilation locations. Finally, they are provided with two drawing activities to construct image locating the abnormal tissue. Only first two activities used in the teaching interviews are used for this purpose because the results of the study show that the third set of drawing activities was not so useful.

7.5 Scope of Further Study

7.5.1: Studies Related to PET Teaching

Duration of Sequencing Effect

The research showed the influence of the sequence of activities in activating students' conceptual resources. The cart activity and the light activity used in the same session had no time spacing. This work can be extended in the future to investigate the persistence and decay of the effect. The cart activity could be introduced to students in a day and the light activity after a hiatus of few days and see if the effect still persists. The decay of the effect can be investigated by providing different amount of time gap between the two activities for different group of students and see how the effect changes with the change of time spacing. The investigation of the sequencing effect can be extended to the sequencing of hints also. This idea can be further extended to any kind of activities or problems beyond that discussed in this research.

Delay Circuit in Optical Model

The light activity did not use a sophisticated system to measure the time difference. The students were provided with the mirrors to make them able see both the lights together. The goal of the research was to see what conceptual resources students activate when they look at the light pairs. Research can be carried out in the future to explore what resources students activate if one of the lights turns on before the other. It will further explain the reasons why students relied on intensity in the light activity before introducing the cart activity. Do they rely on intensity in the light activity just because the activity involved light or because their p-prim of 'sooner the closer' could not be activated because a pair of lights appeared at the same time?

Use of Two-dimensional Collision

This research reported that the students' explanation about the electron-positron annihilation and gamma ray emission is highly influenced by the one dimensional collision demonstration. In future studies students' can be provided with two dimensional situation and see how they transfer that idea in the multi-dimensional situations.

Modes of Analogy

The research pointed out that the students' preferred the mechanical mode of analogy activity as compared to the optical mode. Students' preferences and their learning may not always correlate. The investigation of the students learning and their transfer of learning in different modes of models can be a future research problem.

7.5.2: Studies Related to PER in General

Transfer from Macro to Micro Phenomena

A result of this study indicated the students' transfer of idea of collision and explosion to understand the electron-positron annihilation. This opens an area of investigation of transfer of students' learning of various macroscopic phenomena to microscopic ones. A possible general research question could be "How do students transfer their prior physics learning of macroscopic phenomena to understand microscopic phenomena?"

The research reports that some of the students used mechanical models in light and they explained the motion of the carts in terms of magnetic interaction. It indicates that students use the idea of concrete observable phenomena to understand abstract ideas. This result raised some interesting questions to pursue. A research question along this line would be " what models do students use in explaining abstract processes such as electric and magnetic interactions?"

Transfer from Physics to Other Disciplines

This research is restricted within the investigation of students' transfer from physics to medical technology. Physics is equally relevant in many other disciplines. Evidence of significant transfer in this study suggests expansion of transfer research to other relevant disciplines. Students' transfer of physics learning to engineering, biotechnology and nano-technology are some of the areas that can be pursued. Such effort will provide an avenue to integrate modern technology in physics curricula.

Role of Computers in Physics Teaching

Mainly hands-on activities were used in this study to help students learn and transfer physics learning. The results indicated that the interactive hands-on activity were effective in learning and transfer of learning. The study opens an area of investigation about the role of computer visualizations and simulations in both learning and transfer of learning. The study will suggest if and how the computer simulation and visualization is different in helping students learn and transfer physics learning. A research question might be, “What is the role of the computer simulation and visualization in activation of students’ conceptual resources and facilitation of association of resources?” The findings of the research will inform physics instructors effectiveness of a kind of representation over the other, computer activities versus hands-on activities, in both learning of physics and transfer of physics learning. Based on the results of the study they can decide what modes of teaching activities are better suited in their classroom.

Quantification of Vygotsky’s ZPD

One of the major aims of this research was to explain the students’ learning through social interaction. The research indicated the significant progress on the students’ accomplishments in problem solving and problem solving approach. This progress was explained within the framework of ZPD. It opens an area of quantitative description of ZPD, which was beyond the scope of this research. Number of hints, strength of hints and step to hint ratio provided during the students progression of ideas can serve as the variables to quantify the ZPD.

Optimum Group Size and Student Type

Students participated in 2-persons groups or 3-persons groups in this study. Due to the small sample size systematic argument was not made to report which of the groups was more effective in learning. However, the learning patterns in different types of group were described. I see a future research possibility to investigate the optimum number of students in a group in effective learning of physics. 2-persons, 3-persons, 4-persons groups can be made and investigate how student learning takes place in those different type of groups. The discussion may be possible by using the time on task and level of students’ success as variables. The findings of the study will be useful in choosing group sizes in physics classrooms.

The investigation of student learning with the help of peers of different levels is another area of future research. In this part one can explore if a student learns better with peer of similar ZPD or different ZPD. Students groups could be formed of the similar ZPD and mixed ZPD and look how students perform in those groups. The research will suggest to instructors how to form interactive student groups in different classroom settings. For example, findings will give ideas if it is better to have students in a group with homogenous ZPD or heterogeneous ZPD for effective learning.

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Appendix A - Survey Questions on Radioactivity

Please write comments on questions

1. Have you studied Radioactivity? If yes, when and in what context?
2. Please describe what radioactivity is, if you can.
3. Have you heard about the uses of radioactivity? If yes please describe some uses.
4. What happens to a radioactive substance when it decays? Draw a picture or write in words to describe.
5. What are protons and neutrons? Where in an atom are they located?
6. Have you heard the term “positron”? What is it? If you don’t know, what do you think it should be?
7. What is an isotope? Why are some isotopes stable and some are not?
8. In what type of isotopes does positron emission occur? That is what are some characteristics of positron emitting isotopes?
9. Describe the nature of isotopes that emit alpha particles?
10. What process gives rise to the emission of a beta particle?
11. What holds the proton and neutron together against the force of repulsion between the protons?
12. What do you think a radioactive half life is

    --- The mass of the sample to halve (write the confidence level------------)

    --- The activity of the sample to double (confidence level--------------------)

    --- Half of the original atoms to decay (---------------------------------)

    -----Half the time taken to decay all atoms (-------------------------)
13. If the activity of the radioactive sample takes 2 days to decrease from 100 counts per sec down to 25 counts per sec, this means that the half life of the sample is

    ---- 4 days (-----------------)

    ----- 2 days (---------------)

    ---- 1 day (-----------------)

    ---- None of the above (---------)
14. An alpha particle is made up of

    --- 2 electrons, 2 protons (---------)

--- 2 neutrons, 2 protons (--------)

---- 2 electrons, 2 neutrons (-----------)

--- None of the above (-------)

15. Beta radioactivity is the result of the

---- An electron moving around the nucleus (-------)

----- An electron coming out of the nucleus (-------)

------ Electromagnetic radiation (---------)

----- None of the above (-------------)

16.When radioactive atom emits an alpha particle, the mass number of the atom

------ Increases by 4 (------)

------- Increases by 2 (----)

------- Decreases by 4(-----)

------- Decreases by 2 (-----)

17.When a radioactive material emits negative beta particle, the mass number of the nucleus is

---- Increased by 1 (--------)

----- Decreased by 1(-----------)

---- Unchanged (---------)

---- Not enough information (---------)

18.When a positron is emitted by some radioactive substance the mass number of the nucleus

---- Increased by 1 (--------)

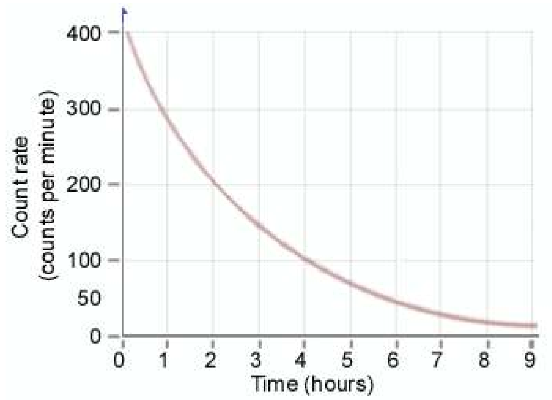
----- Decreased by 1(-----------)

---- Unchanged (---------)

---- Not enough information (---------)

See the plot (Fig A.1) of the count rate measured versus time of a radioactive sample.

Figure A.7.1: Radioactive decay Curve



19.What is the half-life of the sample?

20.How long does it take for all the nuclei in the sample to decay?

21.If there were 5 million nuclei originally, how many nuclei will be left after 8 hrs?

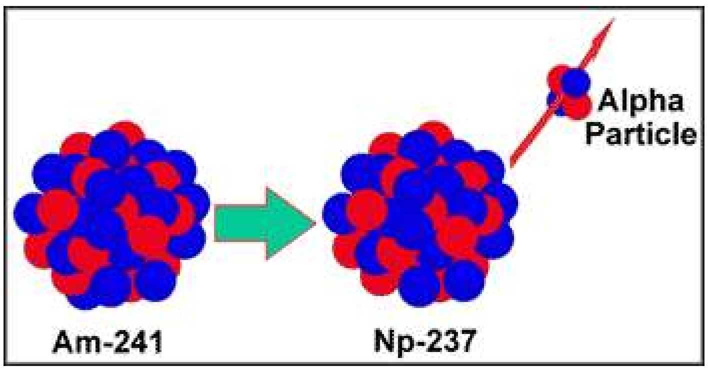
Appendix B - Interview Questions for the Expert Interview

1. I would like to thank you for your help by participating in this study.
2. What is your experience in teaching and learning of pre- med physics course?
3. I would like to know what you know about the physics behind PET. How would you describe the physics concepts behind positron emission tomography?
4. How do you compare X-ray imaging, CT scan and PET scan?
5. What is your opinion about current pre-medical courses regarding medical application?
6. As an introductory level physics student, what did you learn about positron emission tomography (PET) from the course then?
7. As a teacher how do you feel about your students learning about physics of positron emission tomography (PET) process from the course?
8. How do you think the physics concepts should be introduced or taught so that students better understand the physics of PET?
9. We are almost at the end of the interview; do you have any question, comment or concerns at this point?

10. I would like to thank you for your time. Can I contact you later if I need any more information or for additional questions?
11. Thank you once again.

Appendix C - Questions Administered on Students' Pre test on Radioactivity

Figure C.7.2:A Process Taking Place in a Nucleus



1. A) What is happening in the process shown in the figure?

   B) What part of the atom does this process involve?

   C) Why does it happen?

2. Consider the two medical procedures (i and ii) described below:

i. One treatment used with cancer patients called "radiotherapy" involves directing a strong beam of radiation from a radioactive material at the patient's tumor for several minutes.

ii. One medical test used to identify the flow of blood to the lungs involves injecting a small amount of radioactive material into the patient's bloodstream. A detector is then used to track how much of the injected radioactive material reaches the lungs.

Would either (or both) of the procedures described above cause a patient to become radioactive? Explain your reasoning for each procedure.

3. A sample has radioactive atoms. The half-life of the radioactive material is 2 hrs. There are 10 billion radioactive atoms initially present. Initially the mass of sample is 8 gram and volume is 2 cubic centimeters. After 4 hrs,

How many radioactive atoms will be in the sample?

What change in mass takes place?

What change in volume takes place?

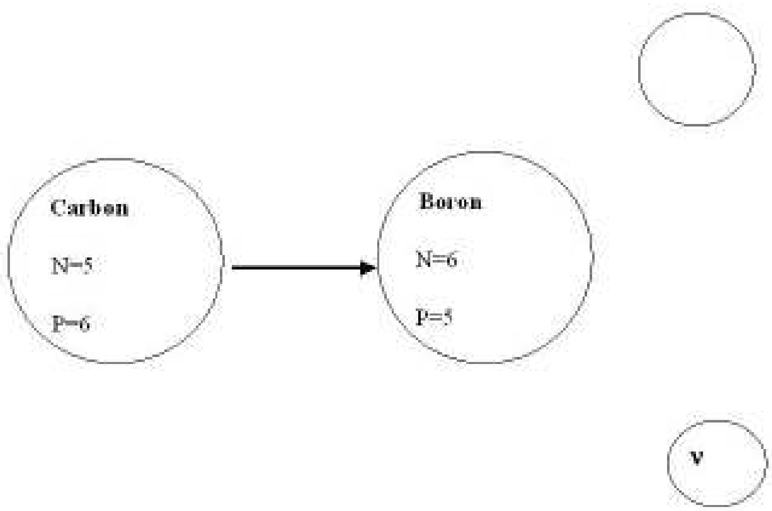
4. You have the following samples of radioactive substances. You want to inject one of them into a patient for the medical diagnosis. You want to pick the one that has a higher amount of radioactivity. Which one would you pick? Why?

Figure C.7.3: Radioactive Samples

Substance **A** 100 radioactive atoms	Substance **A** 1000 radioactive atoms	Substance **A** 10000 radioactive atoms	Substance **B** 100 radioactive atoms

5. What additional information would you like to have to help you answer the question?

Figure C.7.4: Decay of a Nucleus



Carbon on the left side decays to gives three products shown on the right side. ν has no charge or mass. Find the charge and mass number of the particle in the blank sphere above on the right hand side and identify the particle.

Note: N is the neutron number and P is the proton number

Appendix D - Teaching Activity of Radioactivity

Out of a very large number of nuclei, only a few are stable. Most are unstable. The unstable nuclei decay into other nuclides. In this unit we will investigate the nature of decay of the unstable isotopes. Another learning objective in this unit is to understand the reason behind this decay. The process of decay of a nucleus results in the formation of a new nucleus. This process is known as radioactivity and has many uses as well as dangers in our life.

It has a wide range of applications from industry to medicine. Smoke detection, thickness control of metal sheets and radioactive dating are a few common uses of radioactivity. In medicine it is used for therapy and diagnosis. In positron emission tomography, a modern technique of medical imaging, a radioactive isotope that emits positrons is injected in the patients' body. The emitted positron annihilates with an electron in the vicinity, giving rise to gamma rays that then are used for image construction.

EXPLORATION:

#A

In this activity you are going to simulate radioactivity. You have a very large number of dice. Each die represents an atom.

1.1 Take 100 dice having six faces.

1.2 Pour all dice together on the table.

1.3 Take aside all these dice coming up with ones.

1.4 Note the number of dice left.

1.5 Now repeat the steps 2 through 4 with the remaining dice.

1.6 Repeat the process until you finish all dice.

1.7 Plot the number of dice left for each trial versus trial number.

1. 8After how many trials were half the numbers of dice left? Did you end up with zero dice after twice as many trials?

1.9 What kind of functionality between the number of dice left and trial number did you see in the graph?

1. 10 What if you had started with a larger number of dice?

Let's switch our attention from the experiment with a relatively small number of dice (~100) to a situation with a radioactive sample that has huge number of atoms (~10^{23}).

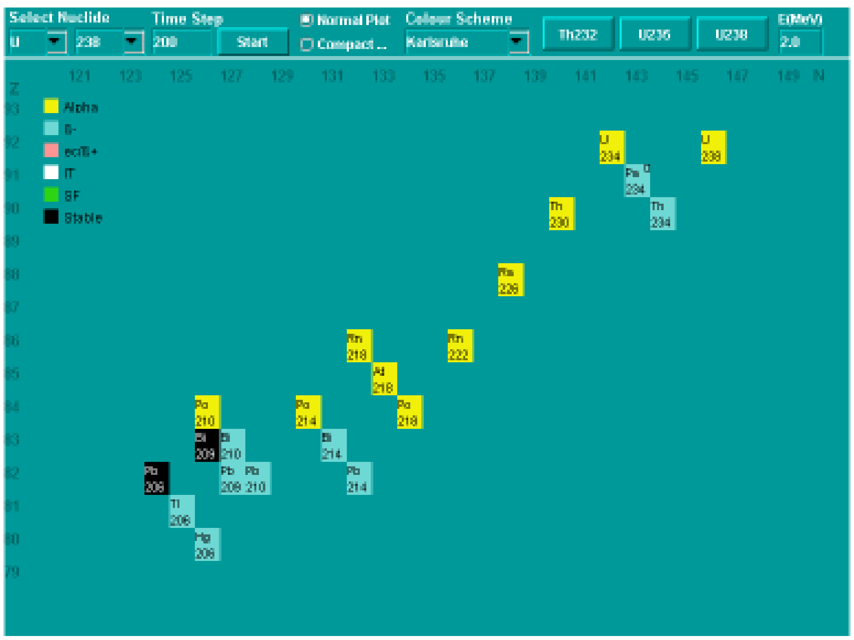
1.11 How long do you think it will take all atoms to decay? When an atom or nucleus decays, does it lose something?

#B

In this activity you are using computer animation. In this Java Applet window you can see a plot of number of neutrons versus number of protons. The position where you are on the curve is indicated by the tiny green square. You can also see the position by the point of intersection of two lines, one going along the proton axis and another along the neutron axis.

Figure D.7.5: Exploration with Interactive Computer Simulation

(Source: http://www.nuclides.net/applets/radioactive_decay.htm)



2.1 Select hydrogen (H) by clicking the selection button for H. Note the number of protons (Z), number of neutrons (N) and atomic mass number (A).

2.2 Increase the proton number gradually by an increment of one each time and write down the stability status.

2.3 Now, increase the neutron number as in step 2 and note the stability status.

2.4 Do this up to proton number 20. Compare neutron and proton numbers for the stable nuclei.

2.5 At this time pick some isotope having Z= 20. Examine the proton and neutron number for the stable isotope. Did you note some difference in the situation here and before when you took Z<20?

2.6 With Z>20, pick a point on the curve above the white (stable) region. Now try to get a stable nucleus from this. You can either increase or decrease the neutron number. Note what you had to do; increase or decrease the neutron number.

2.7 Pick a point below the white region of the curve. This time try to achieve the stable isotope by changing only the proton number.

2.8 Now go to Z>83. Try to get a stable isotope.

2.9 With some value of A other than 5 and 8, try to get at least one stable isotope.

2.10 Try to locate Po with Z=84 and N= 128. Now decrease the proton numbers and neutron numbers each by two. Note what you get. Compare the stability status of the original nucleus and the product nucleus.

CONCEPT INTRODUCTION:

In the activity with the dice you represented each die as an atom of the radioactive substance. When a one was rolled, you removed it; this is similar to the decay or death of atom.

The rate of decay (the number of atom decays per unit time) at a particular instant is proportional to the number of atoms present at that instant.

i.e. $dN/dt = -\lambda N$, where λ is the decay constant and N is the number of atoms at time t. This decay rate is independent of the external factors such as temperature, pressure and the state of the substance. The negative sign indicated that as time progresses the number of atoms decreases.

Upon integration of the equation from t=0 to t we get the equation

$N= N_O e^{-\lambda t}$

Here N_O is the number of atoms at time t=0 and N is the number at time t.

The time after which only the half the original number of atoms is left is called the half-life of the radioactive sample. In our dice activity we replaced time by number of trials. We read this half-life with the help of the graph that was plotted between the number of atoms left versus trial number. From the exponential decay of the graph, it is evident that if the original number of atoms is N, then the number of atoms left after one half life is N/2, that after the two half lives is N/4, after three half lives is N/8 and so on. That’s why you didn’t end up with zero dice after twice the first half life. It is more interesting to note at this point that we still have atoms of radioactive samples that survived though they were formed at the time of earth’s formation. Half lives range from microseconds to 10^{16} years.

The half-life of different isotopes is different. That's why even if we take equal numbers of atoms of two isotopes, the number of atoms left after some time will not be the same for the two isotopes. It is analogous to the water level in two burettes of equal length and equal diameter but different tip size.

In the second exploration activity we clearly saw that there must be neutrons present in the nucleus if the proton number is larger than one. We know that there is electrostatic repulsion between the protons. There is another interaction (strong force) that is effective in a very short distance between the nucleons (neutrons and protons). This is responsible for the stability of the nucleus. The function of neutrons here is to weaken the electrostatic force of repulsion. We noted from the activity that for isotopes having atomic number up to 20 we can see the stable isotopes with Z=N. As we move to the isotopes with Z>20, we do not find any stable isotope with Z=N. This indicates that as nuclear size increases, protons are separated more in the nucleus. The electrostatic force among protons try to dominate the strong force and more weakening of the electrostatic repulsion is required for the stability, which is provided by the increase of the neutron number. When the nucleus size is very large, it tends to give up both neutrons and protons together for stability.

As we saw in the second activity in the Java Applet the unstable nuclei undergo change into the stable nuclei by changing the number of protons or neutrons or both. The curve of proton number versus neutron number that we saw in this activity is called the stability curve. The different regions for the different kinds of isotopes are well described in the curve. When the neutron number is large as compared to that required for the stability, beta emission occurs. The isotopes that we saw above the stability region of the stability curve are therefore beta emitters. In the same way, the isotopes that fall in the region below the stability curve are positron emitters as they possess excess protons and they are converted to neutrons for the stability of the nucleus, giving rise to positrons as the byproduct.

A nucleus is symbolically represented by

$^{A}_{Z}X$ where Z represents the atomic number and A is the atomic mass number.

In the alpha decay process A decreases by 4 and Z decreases by 2. Alpha emission occurs in nuclei that are too large to be stable. In the exploration, we observed this in the region of large Z value. Beta decay occurs when one of the protons or neutrons is transformed into the other.

This process is noticed in the isotopes that are above and below the stability region of the curve that we confronted in the exploration part. Beta particles are either electrons or positrons. In beta minus decay a neutron decays into a proton and an electron whereas in beta plus (positron) decay a proton decays into a neutron and a positron. These processes must obey the conservation of charge.

Here are the few examples of the equation of alpha, beta and positron emission.

Some of the decay equations for alpha emission are given below:

$$^{208}_{84}Po \longrightarrow + ^{208}_{84}Po + {}_2He^4 \text{ (alpha)}$$

$$_{92}U^{233} \longrightarrow {}_{90}Th^{229} + {}_2He^4 \text{ (alpha)}$$

For the negative beta decay let's see few examples:

$$_2He^6 \longrightarrow {}_3Li^6 + {}_{-1}e^0 + \bar{\upsilon}$$

$$_{19}K^{42} \longrightarrow {}_{20}Li^{42} + {}_{-1}e^0 + \bar{\upsilon}$$

Where, $\bar{\upsilon}$ is called antineutrino.

The followings are the decay equation for the positive beta particle(positron):

$$_8O^{15} \longrightarrow {}_7N^{15} + {}_{+1}e^0 + \upsilon$$

$$_9F^{18} \longrightarrow {}_8O^{18} + {}_{+1}e^0 + \upsilon$$

$$_{12}Mg^{23} \longrightarrow {}_{11}Na^{23} + {}_{+1}e^0 + \upsilon$$

$$_{35}Br^{75} \longrightarrow {}_{34}Se^{75} + {}_{+1}e^0 + \upsilon$$

Where υ is called neutrino. The isotopes in the left hand side of these equations are highly unstable, the isotopes in the right side are. This is equally true in the above set of equations.

CONCEPT APPLICATION

Positron emission tomography (PET) uses radioactive isotopes that emit positron and has half-life of few minutes. Identify the isotopes useful for PET application with the help of the information provided in the figures below. Explain the reasons.

Figure D.7.6: Stability Curve

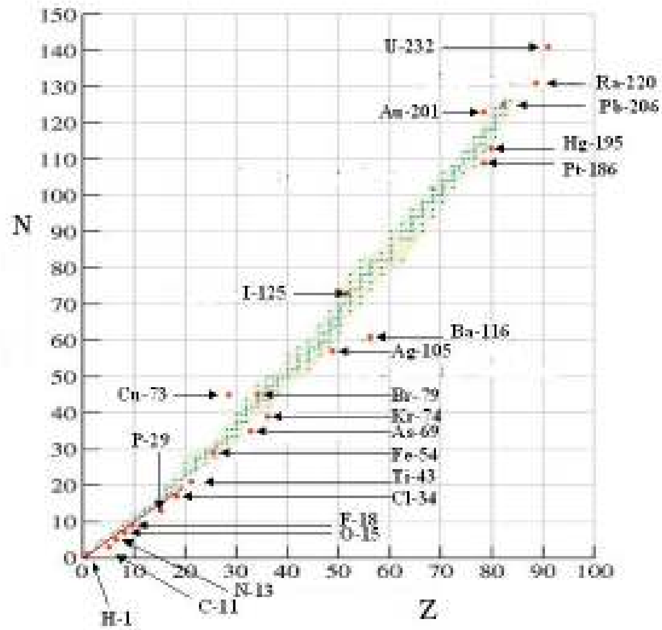
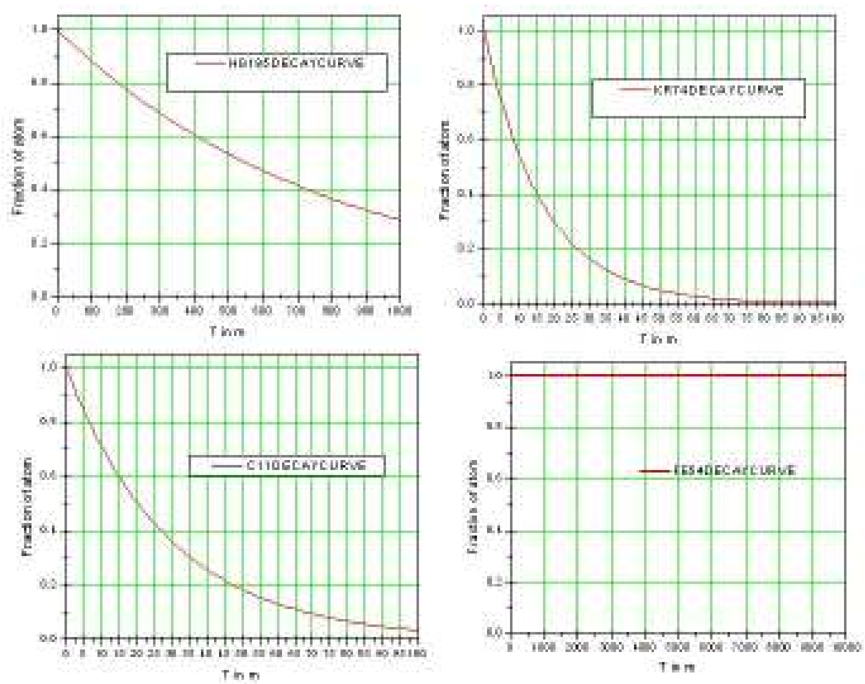


Figure D.7.7: Samples of Decay Curves



Appendix E - Teaching Unit of Mass-Energy Relation and Electron-Positron Annihilation

Contemporary Physics

Spring, 2005

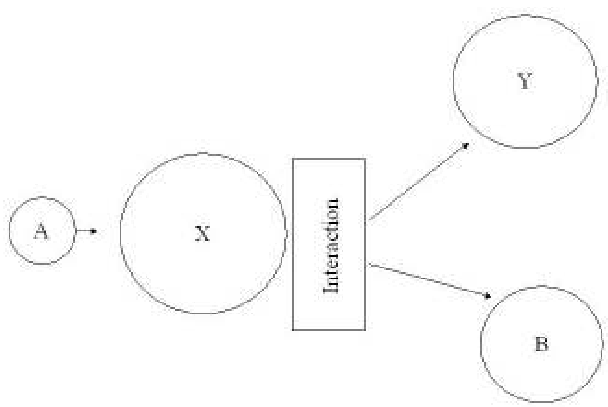
In positron emission tomography (PET) energy in the form of gamma rays comes from the patient's body and is detected. As we have seen the detection of a large number of these gamma rays enables a computer to create an image of processes in internal organs. In this activity we will look at the interaction by the gamma rays are produced and learn something about physics most famous equation, $E=mc^2$.

Exploration

In the previous unit you have seen situations where the energy and mass are conserved individually in a process. Thus, the total energy before the interaction was equal to total energy after the interaction. Also the total mass before and after the interaction were equal. Here you will investigate a slightly different situation.

Consider the process in which we start with two objects, A and X. An interaction occurs and objects B and Y emerge.

Figure E.7.8: Interaction of Two Objects



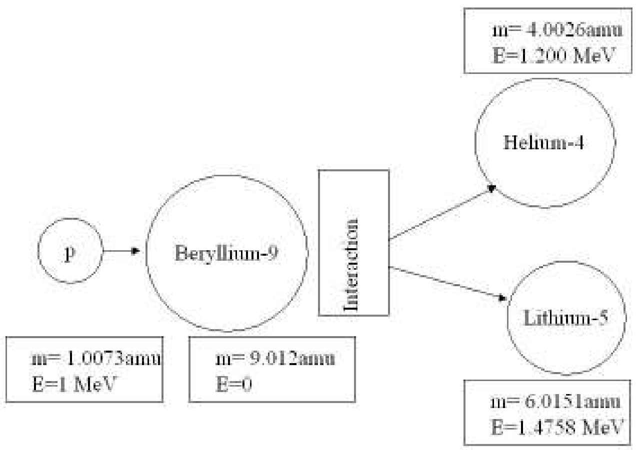
This process is represented by the equation.

A+X → B+Y

We will consider the situation where X is at rest and A is the projectile that has kinetic energy K_A. After the interaction, we see the new products, Y and B. Each of these products both have kinetic energy. The kinetic energy of Y is K_Y and B has kinetic energy K_B.

An example, which occurs in nature, involves the following objects. A is a proton (p), X is a nucleus of Beryllium-9. After the interaction B is a Helium (He) nucleus while Y is a nucleus of Lithium-5.

Figure E.7.9: Exploration 1



1.1 Compare the total kinetic energy before the interaction with the total kinetic energy after.

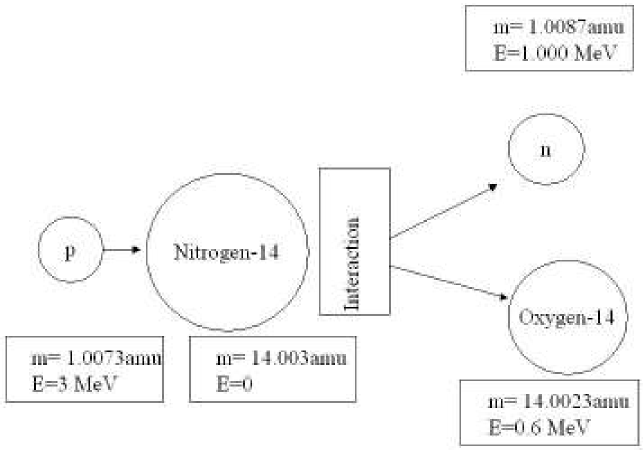
1.2 Compare the total mass before the interaction with the total mass after the interaction.

1.3 Which quantities increased and which decreased during the interaction?

1.4 Where does the increased amount of one of the quantities(either mass or energy) come from in the process?

Now consider the case where a proton (p) strikes a Nitrogen-14 nucleus which is not moving. After the interaction we have a neutron (n) and a nucleus of Oxygen-14.

Figure E.7.10: Exploration 2



2.1 Determine the total masses before and after the interactions. Calculate the change in mass.

2.2 Determine the total kinetic energy before and after the interaction. Calculate the change in kinetic energy.

2.3 How is this example different from the previous one?

2.4 How is this example similar to the previous one?

Now consider the changes in mass and the changes in energy for each example. Using simple arithmetic (addition, subtraction, multiplication or division) try to find something that is the same for the two examples.

Using the information from the two examples, test which one of the following seems closest to correct. In this case ΔK is *change* in kinetic energy while Δm is change in mass. The suffix 1 corresponds to example 1 above and the suffix 2 corresponds to example 2.

i) $\Delta m_1 + \Delta K_1 = \Delta m_2 + \Delta K_2$

ii) $\Delta m_1 - \Delta K_1 = \Delta m_2 - \Delta K_2$

iii) $\Delta m_1 \,.\, \Delta K_1 = \Delta m_2 .\, \Delta K_2$

iv) $\Delta K_1/\Delta m_1 = \Delta K_2 /\Delta m_2$

Concept Introduction:

In both the earlier examples, you saw that whenever mass disappears in an interaction an equivalent amount of energy is evolved. In both the examples, when the change in energy is divided by change in mass you saw a constant of 932MeV/amu (amu is often represented by u).

At this point this unit (Mev/amu) may be strange to you. Electron volt (e V) is the unit of energy.1eV = 1.6×10^{-19} J. Hence, 1MeV = 1.67×10^{-13}. Also, amu is the unit of mass. 1amu= 1.67×10^{-27} kg. From this information we see that the constant 932MeV/amu is actually 9×10^{16} $(m/s)^2$. The square root of which is 3×10^8 m/s which happens to be the speed of light(c). Therefore the ratio of energy difference to mass difference is c^2 that leads us to the relation

$$E = mc^2$$

The equation $E = mc^2$ is one of the most important and most famous to come out of Einstein's special theory of relativity. The equation tells us that mass if a form of energy. The speed of light happens to be the number that we need to convert mass in kilograms to energy in joules.

Mass and energy are two ways of measuring what is essentially the same thing. If a body loses some of its mass m then the amount of energy created is mc^2**.**By this relation we also mean that that if a body absorbs a small amount of energy ΔE then its mass can increase by a very small amount equal to $\Delta E/c^2$. Similarly, if a body emits an amount of energy ΔE, say in the form of light or heat, its -mass will decrease by a tiny amount $\Delta E/c^2$. In both cases, the important and novel claim made by the equation is that the mass of a body can change depending on whether it absorbs or emits energy.

Here we look at an example of the bombardment of a lithium atom (Li) by a proton (p), which produces two alpha particles (α). This reaction is symbolized by the following equation.

$$p + Li \rightarrow 2\alpha$$

In this interaction, there is loss of mass because of the interaction. That is, the total -mass of proton and the Lithium atom is greater than the total mass of the two alpha particles. Thus, the total kinetic energy of the two alpha particles must be greater than the kinetic energy of the proton.

Concept Application:

Each elementary particle has a special partner called its anti-particle that has the same mass but the opposite electric charge. Whenever a particle and its own anti-particle collide, it is as though they cancel one another out. They destroy one another and turn into a flash of pure energy which appears in the form of radiation. One such particle-antiparticle pairs is the electron and positron. They have identical masses (9.1 x 10^{-31} kg =- 0.000548580152 atomic mass units), identical magnitudes of electrical charge but opposite signs.

When the electron and positron interact, they create two packets of energy (gamma rays). These packets also carry momentum. The questions below will help you understand this process.

3.1 What is the minimum number of such objects produced to conserve momentum?

3.2 How do you compare the energy of the objects if they are identical?

3.3 How do you calculate the total energy?

3.4 Is there any change in direction and energy if the electron and positron already have some kinetic energy?

The process discussed above is called positron electron annihilation. It leads to the gamma rays that are detected in positron emission tomography.

Appendix F - The Light Activity Worksheet Used for a Students

Positron emission tomography is a medical imaging technique that is capable of showing how an organ is functioning. It uses positron-emitting (electron and positron are identical other than electron has negative charge and positron has positive charge) isotopes as the tracer. The isotopes are injected to the patients' body as radiopharmaceuticals. The isotopes emit positron. Once a positron finds an electron in the vicinity annihilation takes place, giving rise to some radiation. The radiation is detected and image is reconstructed. The tracer is distributed throughout the body. Its concentration is more in a region of suspected part (subject). As a result more radiation are produced from that region.

This set up gives us the representation on what occurs on the positron emission tomography image reconstruction process. You can turn on the lights with the help of the rotary switch. Lower scale around the cylinder denotes the angles in degrees.

1) Rotate the switch and find the pattern of light on screen. Note down where you see the light spots.

   Turn the knob… see the lights… get sense of what's going on.

2) Now locate the light spots on the provided sheet of polar graph paper with labeling when they occurred.
3) Draw the lines joining the respective spots to find a pattern. What did you notice in the overall pattern?

Locate the corresponding spots on a circle on the provided sheet of paper…. Label the incident number…. Join the points with corresponding numbers…. See the overall pattern.

4) Assume that individual pairs of light are produced from the different events. Considering momentum conservation where do you think the events took place?
5) Now, PET uses this process in image reconstruction process. Detectors are along the cylinder like you saw in the model. Anything that is going on inside the part of investigation is not visible to a physician like the events inside the cylinder are not visible to you. A form of radiation reaches to the detectors and some device (photo multiplier tube) detect them. The event that produces the radiation is electron positron annihilation. A positron is identical to an electron but it has opposite charge to that of an electron. In annihilation mass is completely converted into energy. (Need more explanation on annihilation). The positron-emitting atoms must therefore be injected in the organ and you know that electrons are already there (actually everywhere other than in vacuum). Determining how the positron emitting atoms are distributed in certain organ, physicians are capable in figuring out the affected region.
   a) Describe how the positron emitting isotopes distribution is figured out just by detecting the radiation by detector.
   b) What are the conservation laws apply in the process?
   c) What could these things be that make the detector activate?

Appendix G - Worksheet Used in Laboratory Class for the Cart and the Light Activity

Measuring without seeing

2. Introduction to Medical Scans

Contemporary Physics Laboratory

Physics 452

Spring, 2006

Contemporary physics is the foundation of several types of scans used in modern medical diagnosis. In the diagnosis procedures the physicians does not wish to look directly at the organs of interest because the process of looking either destroy or do damage of organs. So, in some way they are different from the atomic experiments where we can never see the objects. In other ways they are similar because we are building models be looking at the results and using basic physics. Thus one works backwards to determine where the interaction occurred and what the information about it infers. To understand some parts of how physicians use their computers to reconstruct information about the inside of the body, we will work with the classical physics analog to the actual situation. The set of experiments here will show how classical physics is a part of the data collection and image reconstruction process.

Goals

After completing this experiment you should be able to:

- use a mechanical analog to see how one can locate a point of interaction from a time difference as is done in positron emission tomography.
- use an analog using a series of lights to learn about another aspect of positron emission tomography

Equipment

Carts on a track, timers. Lights

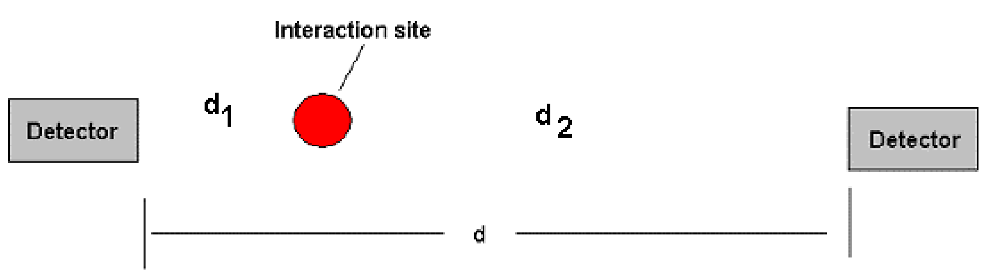
A. Determining the location of an interaction with time measurements

Positron emission tomography (PET) is used as a way to create images of the inner parts of the bodies without surgery. Like x-rays and other forms of medical imaging PET can be used to learn about functioning of certain organs. It has been particularly useful in helping us understand thinking processes by showing changes in brain behavior. Throughout the semester we will be learning about different aspects of physics which go into making PET work. This first one is learning about how one can determine the location of the interaction involved in PET from a rather simple time measurement.

PET images are created by injecting a radioactive substance into the patient. The substance undergoes beta transformation and emits a positron. The positron is identical with the electron except that it has a positive charge. When a positron and electron interact, the result is two gamma rays. When the interaction occurs, the positron and electron are generally not moving and thus have zero momentum. Because of momentum conservation, the gamma rays momenta must add (as vectors) to zero. Thus, they must move in opposite directions. Further, gamma rays are a form of high energy light, so they move at the speed of light. Thus, we know their speed and that they move in opposite direction.

To understand how we can determine from this limited information the location of the interaction, consider the arrangement shown in the figure below.

Figure F.7.11: Hidden Event



d_1 will be the distance traveled by one gamma ray while d_2 is the distance traveled by the other. Thus,

$$d_1 + d_2 = d$$

$$\begin{aligned}
d_1 &= vt_1 \\
d_2 &= vt_2 \\
d_1 - d_2 &= vt_1 - vt_2 \\
d_1 - d_2 &= v(t_1 - t_2) \\
\Delta d &= v\Delta t
\end{aligned}$$

Thus, we can determine the difference between d_1 and d_2 by only knowing the difference between the detection times and the velocity at which the objects are traveling.

In the space below use the above equations to write derive equations for d_1 and d_2 in terms of v and Δt.

To see how this works with large objects you will use two carts on a track. The carts have strong magnets in one end. By pushing the carts gently toward each other so that the magnets interact they will repel and move toward the end of the carts.

1. Follow this procedure and measure the speed of the carts.

2. Now, place a barrier so that most of you cannot see the release point. One of you should release the plungers while the others measure Δt. Record you measurements and calculate the interaction location below.

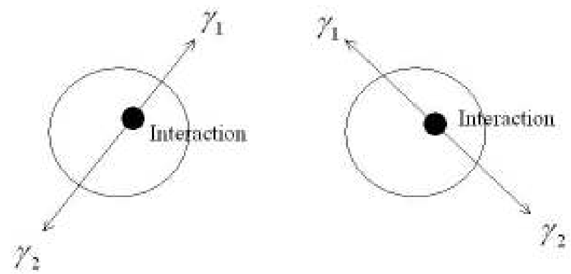
3. Repeat this activity with a few more release points.

4. Discuss the uncertainty in your determinations.

B. Using multiple measurements to find a location in 2 dimensions.

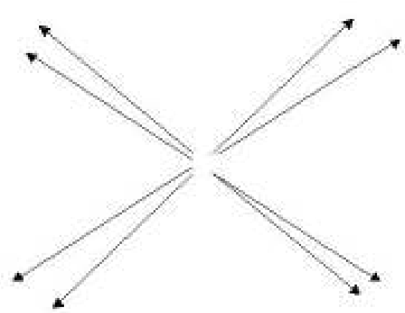
In part A we dealt with only one dimension. In a more realistic situation the two gamma rays will be emitted in variety of directions. However, because of momentum conservation they will always be emitted in exactly opposite directions. Two examples of how the gamma rays will be emitted are shown in figure. By detecting the angle for a large number of pairs of gamma rays, we can determine the location of the events which created them. This detection process is the pat of the image reconstruction.

Figure F.7.12: Gamma Detection



In PET many electron-positron interaction will occur in a very small region of the body. Thus each pair of gamma rays will be emitted in a relatively small region. Figure represents several events which occurred in the same general region. Each pair of gamma rays, in effect, point back to the interaction region. One aspect of PET image construction is to look at many such pairs and try to determine where the majority of the interactions are occurring. Of course in a real situation they will not all be exactly the same place, so some uncertainty will be present.

Figure F.7.13: Multiple Gamma Detection



The experimental set up provides an analogy to help you understand this aspect of the image reconstruction. Pairs of small lights represent the detection of the two gamma rays from a positron-electron interaction. The basic goal is to look at many such events and determine the most likely location of the majority of the events.

You turn on pairs of lights with the rotary switch. The lower scale around the cylinder denotes the angles in degrees.

1. Rotate the switch and record (in words) your observations of the pattern of lights on the screen.

Each pair of lights is an analogy with detection of two gamma rays from one interaction.

2. Now use the graph paper with the angles marked on it to record the location of the pairs of lights from one annihilation. Think about what we did in part A about momentum conservation. From only the information of the lights pair what can you say about the possible location or locations of the events that would have caused the lights to occur where they did?

3. What can you not determine about the location or locations?

4. Now record on the graph paper the locations of the lights for all pairs of events. Be sure to label each pair so that you know which one go together.

5. Follow the procedure in part 2 above to indicate the possible locations of the events that created each such pair of lights. Draw appropriate lines on the graph paper. What do you notice in the overall pattern?

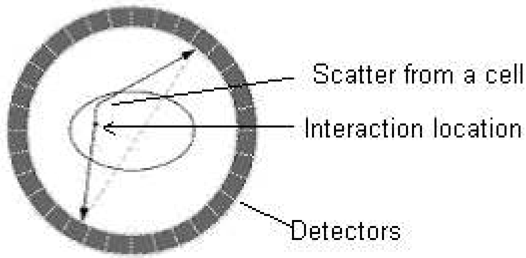
6. As discussed above, events that create the pairs of gamma rays tend to cluster in a region of the patient. (We will learn why later.) Assume that individual pairs of light are produced from the different events but are likely to come from the same region. Considering momentum conservation where do you think the events took place? Explain your answer.

PET uses this process in image reconstruction process. Detectors are along the cylinder like you see in the model. Anything that is going on inside the part of investigation is not visible to a physician like the events inside the cylinder are not visible to you. Gamma rays reach the detectors and some device detects them.

C. Some corrections that physicians must consider

In real PET 3 dimensions are involved. Thus, one of the photons could scatter off another object rather than going straight to the detector as shown below.

Figure F.7.14: Scatter Event



Adapted from:
http://depts.washington.edu/nucmed/IRL/pet_intro/intro_src/section2.html#2.3

This situation represents an error that could be introduced to the creation of the image.

Based on momentum conservation discuss what error would occur if one gamma ray went straight to the detector while the other one bounced off a cell in the brain before going to the detector as shown above.

Based on using the time difference to determine the location of the interaction what error would occur from the situation in the diagram above.

Appendix H - IRB Consent Form

KANSAS STATE UNIVERSITY

INFORMED CONSENT TEMPLATE

PROJECT TITLE: Modern Miracle Medical Machine

PRINCIPAL INVESTIGATOR: CO-INVESTIGATOR(S): Dean Zollman(PI)
Bijaya Aryal(CI)

CONTACT AND PHONE FOR ANY PROBLEMS/QUESTIONS: Dean Zollman (785) 532-1612

IRB CHAIR CONTACT/PHONE INFORMATION: Clive Fullagar, Chair of Committee on Researh involving Human Subjects
1 Fairchild Kansas State University, Manhattan KS, 66506, (785) 532-3224

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

SPONSOR OF PROJECT: NSF

PURPOSE OF THE RESEARCH: Investigating students' knowledge construction of physics concepts in the context of medical imaging processes

PROCEDURES OR METHODS TO BE USED: Interviews

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

None

LENGTH OF STUDY: 2 meetings (approximately 1 hr each)

RISKS ANTICIPATED: No known risks

BENEFITS ANTICIPATED: Deeper understanding of physical phenomena

CONFIDENTIALITY: The participants' performance and/or statements during interview and in survey will not be disclosed with 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: ____________

Witness to Signature: (project staff) ____________________ Date: ____________

Appendix I - Protocol for Individual Teaching Interview

Interviewer (teacher): BA

Observer:

Participant (student):

- I would like to thank you for your participation in this study.
- We will have two sessions of teaching activity. One session is today and the next part is on our next meeting. Each session will be approximately one hour long.
- Your responses, answers or performances are not considered as right or wrong. Your performance in these sessions will not affect your class grade in any way.
- The activities of both sessions will be videotaped. The video will not capture your faces however, and your identity will not be disclosed. Do you have any problem with this taping?
- You have right to discontinue your participation in this study at any point.
- If you agree to participate in this study please sign the consent form then we will advance to do the activities.

Session 1:

We have two sets of activities today. From these sets of activities you will learn how to locate the hidden interaction spots with the help of limited information.

Activity1:

We have two carts that move in opposite directions along a track. These carts push against each other with the help of magnets attached to both of them.

a) Calculate the speed of both the carts after they repel each other. What data would you need to collect (measure) in order to calculate their speeds?

Figure I.7.15: The Cart Activity

b) (After the carts hidden and released) where did I release the carts?

c) How do you find the exact location of carts release when they are behind the barrier?

d) Discuss the uncertainties or sources of error in your determinations.

e) Also estimate the size of the uncertainty and how to reduce it.

Activity2:

In activity 1 you were locating an event in one dimension (along a line). Now you are exploring to locate many events in two dimensions (on a plane). In this activity you will be able to see two light spots on the screen at a time. Actually both these light spots result from a single interaction. That means only when both lights are on does an event happen. You will then be looking at 12 such events and determine the region where the majority of such events occur.

Figure I.7.16: The Light Activity

a) When you turn the knob for one complete rotation describe whatever you see or feel? What overall impression did you get?

b) Now indicate (or record) on the graph paper the positions of a pair of light spots when the knob is at a position. Realizing the fact that both the spots are the result of an event and law of momentum conservation holds what can you tell about the possible location or locations of the event?
c) What can you not tell about the location or locations?
d) Now record on the graph paper the locations of the light for all pairs of events. Be sure to label each pair so that you know which ones go together
e) Repeat step b for all pairs to indicate the possible locations of the events. The events are occurring at some region. With the help of the drawing so far where do you think the majority of such events took place?
f) At what point are the ideas from activity 1 useful in locating the events in activity 2

See you in the next session. Confirm the time for the next session.

Session 2:

In positron emission tomography (PET) you can learn about the functioning of internal organs by knowing how the radioactive tracer diffuses in different regions of an organ. The infected region or the growing tumor has more concentration of the radioactive isotope or the tracer labeled with the radioactive isotope.

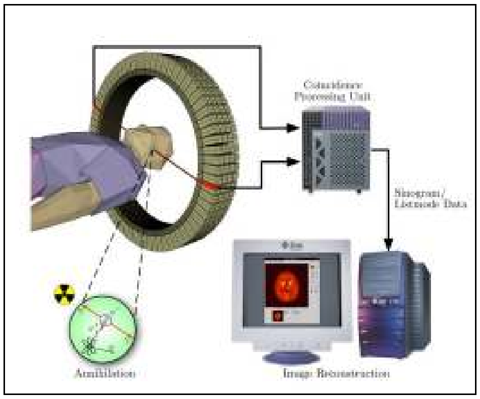
a) What do you think it might be (after showing the PET scan)?
b) Describe what is going on here (after showing PET scanner and detectors, patients lying on PET table).

Students are provided information about injection of atoms, positron, annihilation and gamma ray production. The following questions are asked thereafter.

c) What is minimum number of gamma rays that can be produced by a single annihilation event? Why? Hint: the electron-positron pair has zero momentum just before they meet.
d) The gamma rays emitted from the annihilation have energy. Where did this energy come from?
e) What are the directions (relative direction) of gamma ray? Why?
f) Where will the gamma rays be detected?
g) How many detectors do you need to detect annihilation? Why? How is the information of path of gamma ray stored?

Coincidence detection figure is then shown to students and then the following questions are asked.

Figure I.7.17: Annihilation Locating

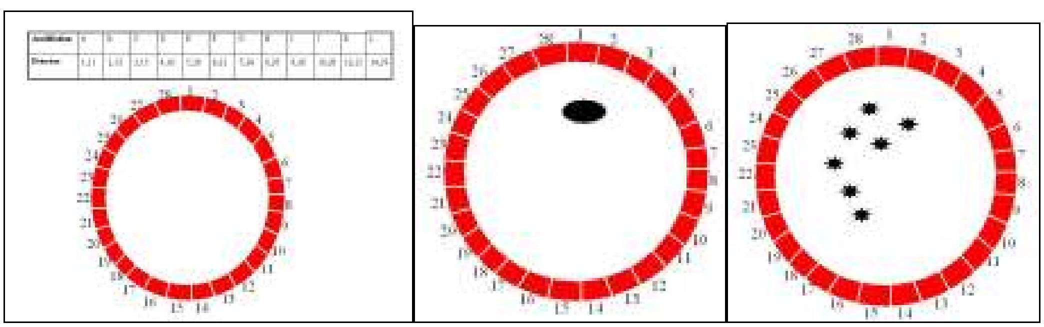


h) How will you determine the position where annihilation took place? How do we know the exact place of annihilation? What mathematical equation will be used to find the location? What are possible errors and uncertainty**?**

i) In what way is the position of tumor identified?

j) Complete the following drawing activities and compare them.

Figure I.7.18: Drawing Activities



Questions to ask before the end of the session

1) Did the first session or the courses help you answer these questions? If so, in what way?
2) Do you think the different activities or the different sessions in this process are connected? If so, how? If not why not?
3) Identify the physics concepts used in this process or activity.

4) How did this activity help you to understand the knowledge of momentum conservation and image reconstruction?
5) Which of the activities or discussions helped you to better understand and use physics concepts in the medical imaging process?

I may need your help in future. Can I contact you to ask you something regarding this project?

Appendix J - Group Teaching Interview Worksheet

First Session

Locating Unseen Events:

In the following activities you will do some experiments to determine the locations of hidden events. You will have access with limited information and using that you will attempt to determine qualitatively and quantitatively about the locations. These kinds of problems are common in physics where we obtain the information about objects or events even though they are not directly visible to us. As a practical application, locating unseen events is widely used in medical technology.

Activity 1:

In this activity you are using two magnetic collision carts. At first play with these carts on the track and get some ideas on how they behave.

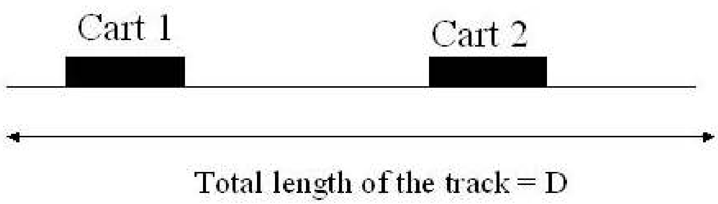
1.1 Bring the carts close to each other and release them. What are they doing and why?

1.2 How do you compare the velocities of the carts?

1.3 What is the basis of your answer above?

Now, I put a barrier that covers the track and you can see only the ends of the track. In this situation you can’t tell when and where I released the carts. Then I will release them from different locations. You can see them only when they reach to the end of the track. Based on that information you will try to determine the location. For each event of releasing the carts, answer the following based on your observation.

Figure J.7.19: Carts on Track



1.4 Roughly, where did I release the carts?

1.5 What assumptions did you make to locate the event?

Earlier you tried to determine the location qualitatively. Now I want you to determine as well as you can the location of carts release.

1.6 What information do you need in order to find the exact location?

1.7 What equipment in particular would you need to measure the quantities and how do you measure it?

1.8 What equation or equations will be useful here to determine the location?

1.9 Discuss the error in this experiment.

Now one of you will release the cart and another will be behind the barrier observing the carts at the ends of the track. After then the observer will perform essential measurements. Finally you both work together on the observer's measurements and determine the location of cart release. Show your work below.

Activity 2:

In this activity you will try to find the locations of events that produce light. Here we have simulated the explosions inside the plastic cylinder. An object at rest explodes into two parts and travels to get onto the wall of the cylinder. You can see the lights but not the source that produces them. You will then work on several light emitting events and try to determine where these occur inside the cylinder.

When the switch is activated you can see two lights resulted from an explosion. When the switch is rotated to another position you will see another pair of lights corresponding to another explosion event and so on.

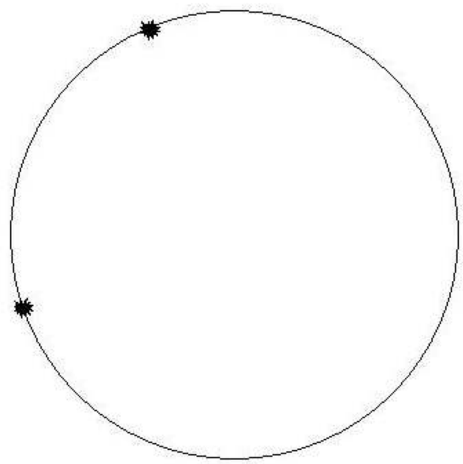
2.1 Observe the lights when the switch is at different positions. Did you notice any trend of the light positions while making the complete rotation of the switch?

2.2 Did you notice anything different from your original prediction?

2.3 What do you expect regarding the locations of explosions?

Now you are going to focus on only one event. Eventually you will get the idea of the location of the event. As discussed earlier one event gives you two light pulses and that is appeared on the wall of the cylinder. For a particular position of the switch, locate on the sheet of paper the positions of the light pulses.

Figure J.7.20: A Pair of Lights on the Cylinder



2.4 How will the explosion bits move so that those lights reach the observed positions?

2.5 Draw the path the bits travel.

2.6 What is the reason that they should move the way you have drawn?

2.7 At this point what can you tell about the location or locations of the event?

2.8 What can't be ascertained about the location or locations at this point? Is there any measurement that would help you to determine the exact location?

2.9 What factor or factors do you consider in locating the events usually?

2.10 What more information do you want to know to find the exact location?

Now, record the light positions in the provided circular graph paper and label the lights. While labeling, remember that a pair of lights is resulted from an event.

2.11 Draw the pattern on the graph paper representing the paths for products of each event.

2.12 What additional information can you tell about the locations of events at this point?

You did two activities today, one using carts in a track and another using lights inside a cylinder. You tried to locate the hidden events with the help of limited information.

2.13 Which of the above activities gives a more accurate idea on location for individual events? Why?

2.14 What are the commonalities and differences in those activities?

2.15 What are the main physics concepts involved in the cart activity and light activity?

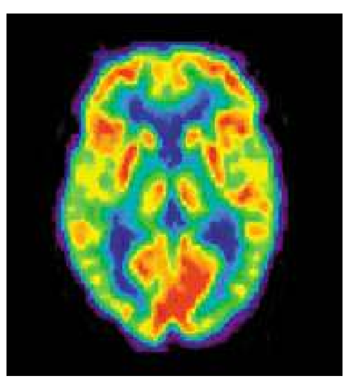
2.16 In what way is the idea of locating events in cart activity applicable in the light activity?

Second Session

Positron Emission Tomography:

The following picture shows a positron emission tomography (PET) scan of brain. Positron Emission Tomography (PET) is a medical imaging technique used to detect changes in the cellular function of internal organs or tissues without doing surgery. The physiological changes in the cellular function are pictured that enables to diagnose certain diseases at their earliest stages.

Figure J.7.21: A PET scan



http://en.wikipedia.org/wiki/Image:PETscan.png

A drug possessing a special type of atom is administered to the patient by injection which localizes in the region of the abnormal tissue or organ. After 30-40 minutes of the injection the patient is taken to the scanner. You can see a patient on the PET scanner machine below (Fig.2) and also the detector configuration (Fig.3). A positron, which is a positively charged particle having equal mass and equal magnitude of charge as that of an electron, is emitted by the atom by the process of beta activity. The positron then travels a short distance before finding an electron on the path. Just before they meet the momentum of the electron-positron system can be taken as zero. After they meet the annihilation takes place resulting in the conversion of electro-positron mass into gamma ray energy. The PET scanner detects and records the emitted gamma ray signals. The signals are then processed by the computer to construct the image of the organ or tissue under investigation.

Figure J.7.22: A PET Scanner

http://www.medical.philips.com/main/products/pet/

The above discussion gives you the overview of the positron emission tomography technique. Now you are going to understand the mechanism and key ideas behind this.

Let's spend some time in discussing the electron-positron annihilation and its product.

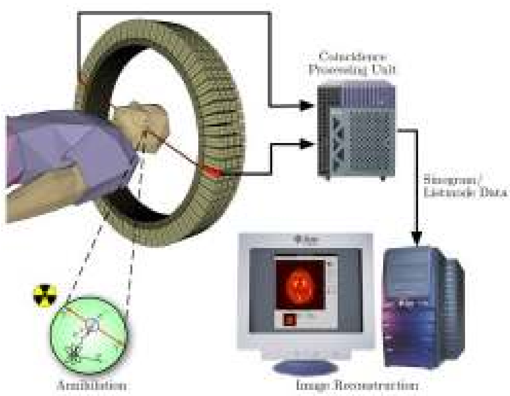
a. When an electron and positron annihilate how many gamma rays in the least should be produced in order to conserve the momentum?(hint: the momentum of the electron-positron system just before annihilation was zero)
b. Draw the path of the ray or rays produced after the annihilation process.

c. What can be the source of the energy of the gamma rays?

d. What conservation laws are involved in the process of electron-positron annihilation?

Now you are going to investigate the working of the PET machine. The Figure below shows a spot where annihilation is taking place. The annihilation location is inside the head which is not visible externally. The machine figures out such annihilation spots and eventually creates images of the tissue. So the most important function of the machine is to determine the exact locations of many such annihilations.

Figure J.7.23: Annihilation Location Activity



e. Consider only one annihilation event and refer to the above diagram to describe the process to determine the exact location of the annihilation.

f. What is the basis of your description?

g. Describe how the machine will figure out the abnormal region in the organ.

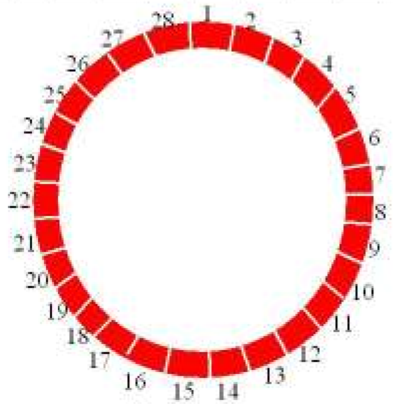
The activities below are related to the image construction process in PET.

Activity 1:

In this activity you are given the data and detector configuration and you need to figure out the region of abnormal tissue or organ.

Figure J.7.24: Tumor Locating Activity

Annihilations	A	B	C	D	E	F	G	H	I	J	K	L
Detectors	1,11	2,13	3,15	4,16	5,20	6,22	7,24	8,25	9,26	10,28	12,23	14,19



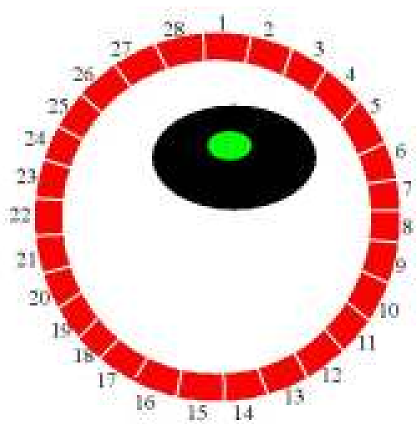
1.1 What caused you to draw your diagram in that way?

1.2 How do you know that the abnormal part of the organ is in that region?

Activity 2:

The numbered red ring in the figure below shows the PET detector surrounding a head represented by black region. The green portion is the tumor in the head.

Figure J.7.25: Annihilations from a Tumor Region



Generate the paths of gamma rays reaching the sensors (detectors) in the given picture (Fig. Act2).

2.1 What are the reasons that justify your drawing?

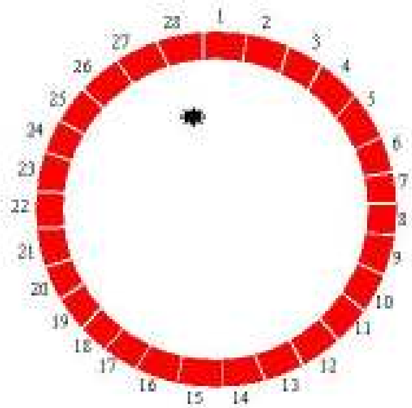
2.2 How do you compare this activity with the last activity?

Activity 3:

Several activities are presented that deal with the annihilation and their detection by the sensors.

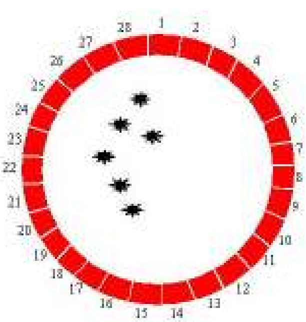
3(a) As the first problem a single annihilation and the detector configuration are presented below. You need to draw the possible paths of gamma ray travel to get to the sensors.

Figure J.7.26: Detecting Annihilation



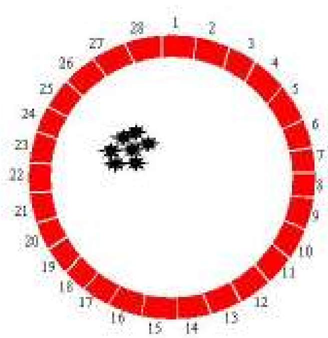
3(b) Continue below the work of drawing the pattern when there are seven annihilation events.

FigureJ.7.27: Detecting Multiple Annihilations



3(c): Also draw the paths of gamma rays if all the events are crowded in a region as shown below.

Figure J.7.28: Detecting Clustered Annihilations



i. Discuss the differences between the drawings of the different parts of activity 3.
ii. How do you compare the activities 3(b) and 3(c)?
iii. How do you compare activities 1, 2 and 3(c)?

Final discussion questions

iv. We did some activities last time and we did some today. Did the activities of last session help you to do some activities today?
v. If yes, in what way did the activities help you? If not, how are the activities in two sessions different?

Appendix K - A Segment Provided for Individual Interview Data Analysis Reliability Test

(Note: Italicized parts are the questions I asked to students)

1.Event location: student tendency of locating events that produce two lights

Statements (after students saw two lights on the two points on the wall of cylindrical container they responded this way, when asked to tell where the event should take place if the event inside the circle is producing two lights)	**Tendency**
Well…if it is one event it is showing up at two different places it will be at the central focal point ….may be reflection or a light source showing up at two different places…possibly	
Just simplicity if two halves of the objects that exploded were of the same	

size then the object have to be in the center for those two balls	
About being in the center …we don't really know…	
It is hard to be something over here (other than center)…could you have one bulb ...from what I know from my experience one bulb here… I mean it could be possible to have anywhere in the circle if you have more than one bulb	
I think half way because just by judging this example looks like the masses are the same…so they gonna have equal velocities	
Two balls come out of one…balls of the same mass…traveling at the same speed so that it will hit the out side circle at the same time…it has to be in between here… I mean proportionally between where they hit	
It makes sense symmetrically I guess…like if you broke a particle in half…if they were equal halves then there would be symmetry so the particle that move in that way is of equal magnitude and opposite direction	

2.Factors considered locating light emitting events: intensity (I), size (S), time (T)

Statements	Factors
To go into the straight line they are going to be equal so…. middle	
What I would think is the light that goes to the shorter distance would be brighter…so like one of the light would be brighter than the other light because if this one had to travel shorter distance it would still have more…it would still have more like … I wanna say force but that will not be the right term …but it would have more power behind it in comparison to that coming from over here	
…the size of the light ….the brightness and everything …all about the same so… I think it takes place her (center)…. I think they were of equal brightness	
…if the amount of light it gets turned on is dependent on the amount of particle it reaches…whatever is reaching then I would say you gonna get	

more light in one than the other…	
…one thing of light come first and next one come first depending …the closer one will come faster than the one which is further away	
…obviously you could know by time but you can't measure time for light…or you could find the distance somehow…the total distance (length of line)	

3.Influence on light activity:

Statements after asking question *(If you use the understanding of carts experiment in the other activity (light) how would you locate the positions in this diagram?)*	Influence
I would move the source either one way or the other depending on each line…say for this particular line …if it hits this one first then I would move the source little bit closer to this side than this side	
…this point right here it will gonna hit over to 2 and on at 10faster than over here at 110 or 180 because it has shorter distance to go…	
ok…from that activity …you could…I guess it depends on the time …the time you saw each of the events and then you will be able to figure out where exactly the event occurred along that line…yeah	
Well…if there were a way to…meaning like…better instrument than eye…then you could measure the time difference…ok we know the velocity of light…we know the speed of light so if you could measure the distance between…oh I am sorry the time in between the light came on then you could guess by doing that	
…this kind of applied in part of the reasoning….it is coming from collision and I assume that measuring like time of light you could like …some how account like time it takes to reach to certain region…with that you can figure out at the angle you can figure out the region…you can figure out where they intersected most a lot of color going on …and then you could use this to figure out where each coming from…which one gonna reach first	

4. Model of light:

Statements	Model
Then may be you are working with heavier weight factor …like if you know the cars… the heavier weight is not gonna go far …so if it has the same velocity and if you have a point over here and whatever and this light has to go so far and this one go twice as long ….	
Mass of tumor …like physical features of like bumps or …this looks like detection of intensity of emission (scan picture pointing)…so I thought that Depending on how long it took to get gamma ray to travel …and whether they encountered the obstacles … And tumor should be in that side ….the tumor would hinder when it travels	
…may be like …it was something like slowing the light down ….it is translucent that's where we can't see through …it will slow the light down…so if they were here (center) there is some kind of mass in it …it will slow the light little bit	
…gamma ray has to travel all the way through…all through the mass of your mouth , your skeleton system and all your epithelial tissue and go out on the other side ….so would assume that it would slow down or it would be altered little bit but go through all the tissue	

5. Influence on annihilation:

Statements	Influencing factor
An electron and positron collide they produce gamma rays and these gamma rays go in opposite directions and then in another activity…when the carts collided they would also go in the opposite directions	
Because everything is going towards this center so, they would go opposite outside… as these two come together they had momentum towards this center so the rays would go outside opposite to each other	
To keep the direction the same …you don't change the direction…just	

go back and forth	
…paper here is just two dimensional environment…so I can think of two dimension from here to here and drew these various arrows…keeping mind that two dimensional environment…but of course inside the body this event takes place it is 3 dimensional environment…so they could move any direction	
They come together and hit then… I am thinking that you had … I mean two masses they hit though change to gamma ray and I assume that the gamma rays would do like the mass still there and they bounce off	

6.Types of non-scaffolded transfer:

ST: Spontaneous transfer: readily relate back to previous activity

SST: Semi spontaneous transfer: mention the previous activity upon asking

NST: Non-spontaneous transfer: could relate previous activity when asked if related back with any activity

NT: No transfer from earlier activity

Statements	**Type**
(What caused you to answer in that way) …it is like the cars …where the event took place …since you can't time whenever this event took place (refers to the annihilation)…then you could say whichever detector goes first and time it when it goes off and then the time to reach	
(How do you think that the machine will tell you that the annihilation takes place at that location?) As we were going over in a last discussion…you need a time difference …even if it is like a part of the a second between say this one just before this one hit you know it is closer to this part than the center and you can use that time difference and know the velocity of the gamma rays to determine exactly where the annihilation took place	
(Any prior learning prompted at this point?) Last week when did the cake exercise trying to figure out the source of	

light that kinda helped too…	
(Introduce the picture of coincidence detection) how to get the exact location of annihilation? Velocity with which it captures the gamma ray I can tell it …can tell about here (detector)…. can't tell how far from here …I can't tell how to get the exact location… because I never saw this machine and don't know how it works	

7.Preferred Mode: optical (O) vs. mechanical (M)

Statements	**Mode**
I wouldn't make it circle (light activity) so that I could see that they come at same time…or different timing	
It is physical I can see…but in the light rotating I can't see the balls moving…I can see only the end results so it is harder to fully grasp…little bit more abstract I guess… I need to think about in head but here you can just watch and see what is happening	
We could make to measure the time…make the light bigger so you can see it easier …There is no problem with light	
To realize that … I thought it (light activity) was really helpful because I could figure out where it was depending upon how much time where it hits the edges	
It (cart) is easier…the light is lot harder to measure…like time…cause it moves lot faster than those so it would be easier…it was lot easier to see which one got there faster so I could make you know pretty good guess of where they came from	

Appendix L - Tabulation of Entered Codes for Reliability Test

Entering codes of different categories from the segments

Table L.7.1: Codes labeled

Category and Assigned Code	Examples from Interview Segments
Event Locating arguments Central tendency (C) Non-central (N) Symmetry argument (S)	Well…if it is one event it is showing up at two different places it will be at the central focal point ….may be reflection or a light source showing up at two different places…possibly (C) It makes sense symmetrically I guess…like if you broke a particle in half…if they were equal halves then there would be symmetry so the particle that move in that way is of equal magnitude and opposite direction (S)
Factors to locate events Intensity (I) Size (S) Time (T)	What I would think is the light that goes to the shorter distance would be brighter…so like one of the light would be brighter than the other light because if this one had to travel shorter distance it would still have more (I) …one thing of light come first and next one come first depending …the closer one will come faster than the one which is further away (T)
Influence on light activity from cart activity Time (T) Mass (M)	ok…from that activity …you could…I guess it depends on the time …the time you saw each of the events and then you will be able to figure out where exactly the event occurred along that line…yeah (T)

Momentum (P)	
Model of light Mass (M) Friction (F) Density (D)	…may be like …it was something like slowing the light down ….it is translucent that's where we can't see through …it will slow the light down…so if they were here (center) there is some kind of mass in it …it will slow the light little bit (F)
Influence on annihilation 1d demonstration (1D) 2 dimensional (2D) Cart activity (CR) Light activity (L)	Because everything is going towards this center so, they would go opposite outside… as these two come together they had momentum towards this center so the rays would go outside opposite to each other (1D)
Transfer Spontaneous transfer (ST) Semi-spontaneous transfer (SST) Non-spontaneous transfer (NST) No Transfer (NT)	*(What caused you to answer in that way)* …it is like the cars …where the event took place …since you can't time whenever this event took place (refers to the annihilation)…then you could say whichever detector goes first and time it when it goes off and then the time to reach (SST) *(How will the machine be able to determine the exact location here?)* By the process that we went through last time… knowing the difference in time…. knowing which gamma ray reach the sensor first…so if the gamma ray reaches this sensor first and the computer can figure out which point it is in between the two sensors… (ST)
Mode of learning Optical (O)	To realize that … I thought it (light activity) was really helpful because I could figure out where it was depending upon how much time where it hits the edges

	(O)
Mechanical (M)	It (cart) is easier…the light is lot harder to measure…like time…cause it moves lot faster than those so it would be easier…it was lot easier to see which one got there faster so I could make you know pretty good guess of where they came from (M)

Table L.7.2: Five Researchers' Code Collection

Researchers Categories	ME				LL				ER				DN				DL			
Event location	C	C	N	C	C	C	N	C	C	C	N	C	C	C	N	C	C	C	N	C
	C	C	S		C	C	N		C	C	N		C	C	S		C	C	C	
Factors considered	S	I	I	I S	T	I	I S	N	N	I	A	N	N	I	I T	I S	S	I	I	I
	I	T	T		S	T	T		S	T	T		I	T	T		I	T	T	
Influence in light activity	T	T	T		T	T	T		P	P	T		T	T	T		T	T	T	
	T	M			T	T			T	T			T	T			T	T		
Mechanical model in light	M	F	F	D	N/A	F	F	F	M	M	F	F	M	F	D	D	M	F	F	F
Influence in annihilation	CR	SY	CR		CR	CR	CR		CR	1D	CR		CR	1D	CR		CR	1D	CR	
	2D	L			2D	CR			2D	CR			N	CR			2D	CR		
Transfer	SST	ST	NST		ST	ST	NST		ST	NST	NST		SST	ST	NST		ST	ST	NST	
	NT	ST			NT	SST			NT	ST			NT	SST			NT	ST		
Modes of learning	O	M	O		O	O	O		O	O	O		M	M	M		M	M	O	
	O	M			O	M			O	M			O	M			O	M		

Appendix M - An example of Progression Diagram Provided to the Researchers

Please fill with the proper codes on each of the boxes in the last four rows on each of the tables.

1. What helped students to come up with the ideas at each step? Question /hint, Self and Peer: Codes Q, SE and P
2. What is the strength of the hint? Weak, Medium, Strong: Codes W, M, S
3. What kind of progression you see? Qualitative vs. Quantitative: Codes QL, QT
4. How the ideas are emerging among students? Converging vs. Diverging: Codes C, D

LOCATION OF EXPLOSION ON A LINE

IDEA	Explosion in middle of line	Why not anywhere inside the circle	They are two pieces	Thought about continuous emission of light by explosion	Just two pieces come out
STUDENT	A3	A2	A1	A2	A1
INPUT	What is the location of explosion		Can you explain to him (A2)	Something else explodes giving the lights	

They explode in opposite direction	Same force on both	Don't know which one	Light at the same time	Need to see intensity	Need to do same thing as cart seeing which hits first
A3	A1	A3	A1	A2	A3

Closer to one side because of the brightness of light	Intensity tells more about the energy than the location…need stop watch to measure time between two light hitting	Not possible with stop watch	Possible theoretically
A2	A1	A2	A3

Need length between light positions…speed of light	Time
A1	A3
Is there anything that is necessary to ascertain the location?	

Appendix N - Codes Filled out after collecting all Researchers' Tables

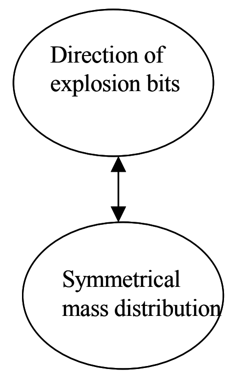
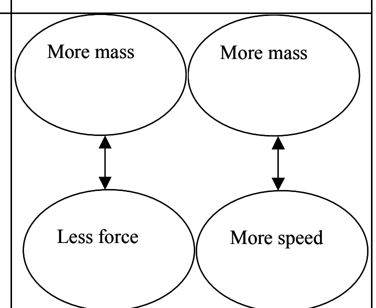
Table N.7.3: Group Interview Progression Tabulated

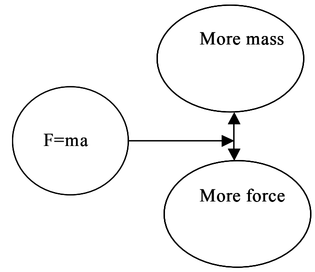
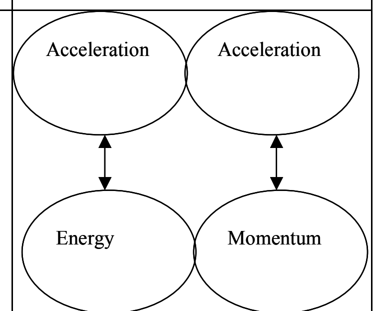
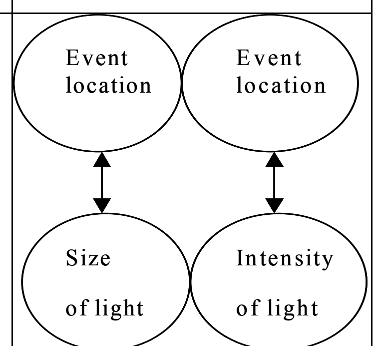
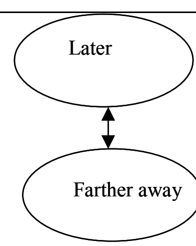
S-STEPS, H-HINTS, QL-QUALI TAVIVE, QT- QUANTITATIVE, CN-CENTRAL/NONCENTRAL, F- FACTORS OF LOCATION, T-TIME, I-INTENSITY, S-SIZE, CQ-QUALITATIVE TASK IN CART, CT-QUANTITATIVE TASK IN CART, UT-UNSUCCESSFUL IN CART

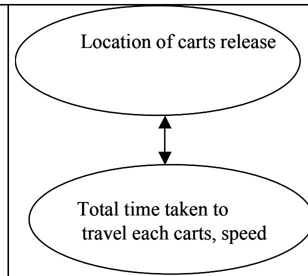
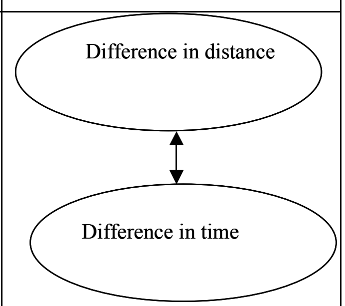
	Cart Location					Explosion location					Number and source of Gamma rays					Annihilation Location in PET				
Group	S	H	QL	QT	CN	S	H	QL	QT	TQU	S	H	QL	QT	F	S	H	QL	QT	
1ACZ	14	4	9	5	N	8	2	6	2	CQ	19	5	14	5	T	8	2	5	3	
2EM	18	6	12	6	C	7	3	5	2	CT	13	4	8	5	T	9	5	6	3	
3 RR	24	16	13	11	N	9	4	6	3	CT	6	4	4	2	T	6	2	5	1	
4MM	18	12	12	6	C	9	5	6	3	CT	9	6	5	4	S	7	5	4	3	
5JJ	18	7	10	8	C	11	6	7	4	CT	9	5	5	4	I	7	4	5	2	
6MI	17	11	9	8	N	6	3	4	2	CQ	12	8	8	4	T	5	3	5	3	
7ASK	23	8	7	11	N	6	3	3	3	UT	12	8	8	4	I	12	7	9	3	
8 AC	19	7	10	9	N	6	2	4	2	CQ	11	4	8	3	T	7	3	4	3	
9MMC	22	9	13	9	N	21	4	14	2	CT	7	3	4	3	T	15	5	11	4	

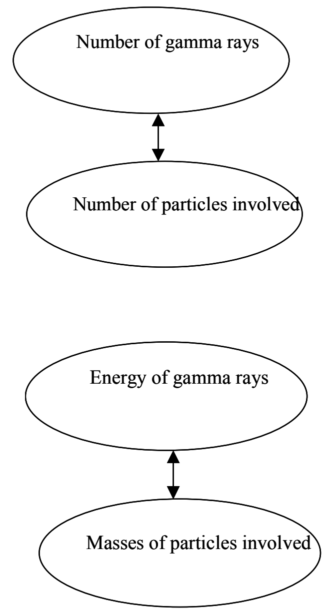
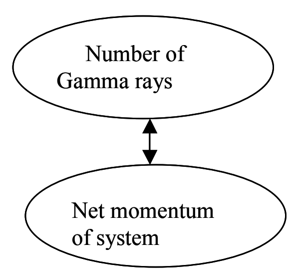
Appendix O - An Example of Individual Interview Association Diagram

Table O.7.4: Association diagram (Individual Interview)

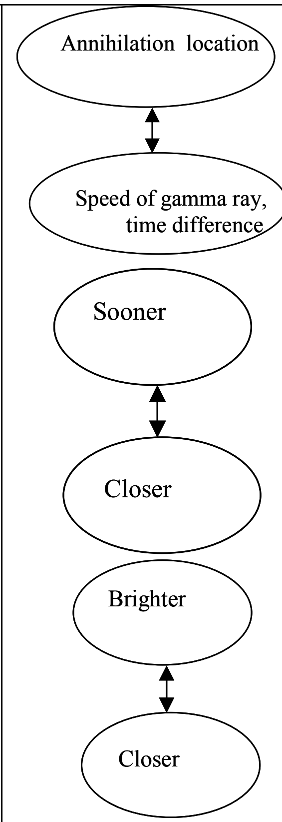
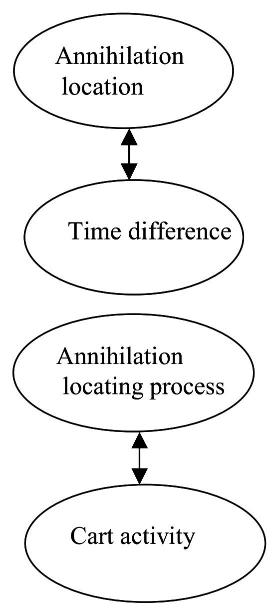
Locating Event Producing the Lights		
Input	Significant Statements (highlighted)	Associations
What are the possible directions of the fragments after the explosion?	…directly opposite to each other and equal in magnitude…it makes sense symmetrically I guess…like if you broke a particle in half…if they were equal halves then there would be symmetry so the particle that move in that way is of equal magnitude and opposite direction	
What if one of the particle is smaller than the other	If the particle is divided unevenly…then I would say that the particle with greater mass would move greater than the particle with the smaller mass…so the smaller part it will still move in the opposite direction but it will have the larger force … the larger mass with the lesser force	

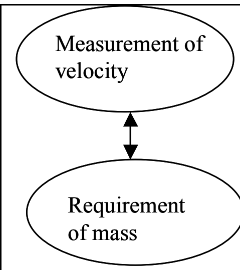
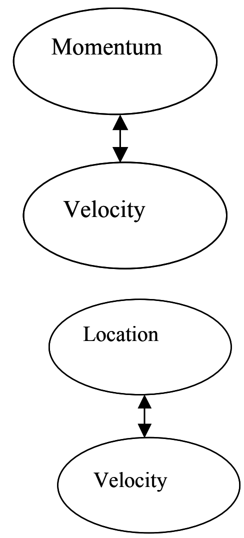
Is there any base for this answer?	I think the law that force equals mass times acceleration…the particle will gonna have the equal acceleration…but one with the larger mass force should be smaller…(writes the equation) I am sorry force is mass times acceleration…so if the mass is larger force will be larger and smaller mass smaller force	
You said equal what…	Equal acceleration…so the energy that was initiated in the explosion is equally distributed between the two and the momentum would be the same …if they have the same mass	
What are the reasons that it must be at the center?	I think it take place at the center because …for example to this one…the intensity of the light was exactly the same…the diameter of the light was the same so I think it should be equidistance from the light source	
Locating Cart Release		
What assumption did you make to estimate the location?	I know from earlier that the velocities should be the same…obviously if comes later means it traveled longer	

How would you determine the exact location?	If I had stop watch or something…measure the time it took on both of them …and then…the velocities will gonna be equal…acceleration will gonna be equal…(writes down some thing) it is my thought process…velocity gonna be equal…they will set equal…plug both the times to figure out the distance from there…what is the distance here?	
Length of track is 120 cm and I give you the speed of the carts…say it is 10 cm/s	…so I can time differences…when this one hits start timer and that one hits end the timer …so we know the change in time …through that find the change in distances from where you released I guess…(thinks for a while)…it is too hard…(after a long pause)…so the distance is gonna …the time difference would …so we know the velocity would be equal to 10…the distance… if I found hypothetically the time 2s…the distance would be 20 cm…so the cart starts here…as soon as I see that cart I start timer…so they should have traveled the same distance at that time….so then I time t2 it will figure out that distance there (distance difference)…so then after that the remaining distance should be the half of that…so whatever	

Gamma Rays in Annihilation		
At least how many gamma rays should be produced in annihilation?	…may be one for each one of them…because if you have the mass and energy so if you have two masses then your energy would be bigger than if you had only one mass so you should get more gamma rays…….or how many or whatever should be produced should be the…close to the energy produced by the gamma rays should equal the energy…that the potential energy times the mass of the positron and electron …probably times their speed ….or actually the gamma rays should be equal to the potential energy ….because potential energy is figured out in mass and speed ….and distance…so I would say no more than two….that was the guess…	
The system has zero momentum …so at least how many gamma rays should be produced if you think about the momentum conservation?	If momentum should be conserved there should be none	

Where does the mass go?	… momentum says there shouldn't be any but the law of conservation of energy and law of conservation of mass says there should be…something has to go somewhere …there is probably one produced	Gamma rays production ↕ Mass conservation
Consider gamma ray traveling in a direction	…do gamma rays produce like circles…or they just come in one direction?	Gamma rays ↕ Expanding circles
In just one direction	Well there gonna be two… because there gonna be one in each direction…they are coming to each other …so there is net momentum equal to zero…but we still have to have net momentum equal zero…so there gonna be a gamma ray given off in this direction and there gonna be given off in this direction…because they will gonna cancel each other out…	Cancellation of momentum ↕ Momentum in opposite directions
Annihilation Locating		

I want to show you the picture (coincidence picture). How will the machine tell the exact location of annihilation?	You probably need to measure the speed of the rays getting to the detectors because if it took place at dead center right at the middle of your head then probably it goes straight down then they will reach at the detectors at the same time…if it took place over here then the one in this side will get the ray sooner …and I don't know if the intensity is important of gamma ray but I would assume the one that travels the least distance probably need to be more intense….but I don't know for sure …. I don't know much about it…gamma rays	
What caused you to answer in that way?	It made me think very similar to what we have the carts on the track going and could not see… I couldn't see exactly when it released and figured out the distance where it was…so in here where the annihilation taking place might be close to one…one side of the body in this side of my head or something that one detector over here gonna detect faster than over there…exactly obviously 180 degrees…but use that time difference and determine the exact location where that is taking place	

What else we need to know?	…you need to know more that just time …you need to be able to figure out …like I guess you said momentum …because if gamma ray doesn’t have mass then you can’t measure their velocities	
You said if gamma ray doesn’t have mass we can’t measure what? I want to hear more about it.	I said if it doesn’t have mass then it I would think it really doesn’t have velocity…but I guess it could…I was just thinking that …I don’t really understand…I mean momentum to me is kinda like velocity…momentum is just like how fast it is traveling and so …it has momentum so it has velocity …I would think that it has velocity but it doesn’t have mass …it doesn’t make sense …so you wanna measure it’s velocity or its speed	

Appendix P - An Example of Group Interview Association Diagram

Red color in association diagram refers that the students just wrote the answer in the work sheet and didn't tell anything about that during discussion

Blue color in association diagram refers the association made by the students after changing their idea during discussion in groups

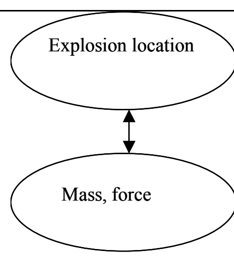
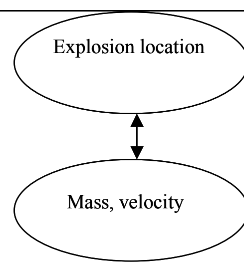
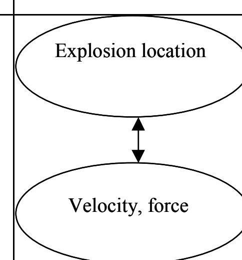
Table P.7.5: Association Diagram (Group Interview)

Significant Statements	Association (Harry)	Association (Adriano)	Association (Leonardo)
Cart Motion			
Question: Discuss the motion of the carts. Adriano: ok…the carts repel each other…probably because… Harry: feels like a magnetic force…the magnetic force repel each other… Adriano: similar poles repel	Direction of carts ↔ Magnetic force	Direction of carts ↔ Magnetic poles	Direction of carts ↔ Magnetic force

Question: How do you compare the speed of carts? Leonardo: it is the magnetic strength…if only the magnetic field…. Harry: Create the same force…or just the …they have the same velocity Adriano: because they traveled equal distances before they stopped…	Speed of carts ↔ Magnetic strength	Speed of carts ↔ Distance traveled	Speed of carts ↔ Magnetic strength
Question: qualitatively estimate the location of carts release. Harry: that one hit that end first…probably they were close to each other Adriano: they were pretty much close to the middle… Leonardo: close to the center	Quicker ↔ Closer	Quicker ↔ Closer	Quicker ↔ Closer
Question: what assumptions did you make to predict the location of release? Harry: we assumed that they traveled with equal velocity…they were released at the same time Adriano: we assumed the	Location ↔ Speed and time	Location ↔ Initial momentum	Location ↔ Time , speed

initial momentum was zero…they were already not in motion			
Question: what information do you need to find exact location? Adriano: probably need some kind of time… Harry: yes…we need time each one to hit the ends…we also need velocity of the carts…of each cart…we are assuming that they have the same velocity A2…velocity towards at the ends	Location of cart release ↕ Speed of carts	Location of cart release ↕ Time measurement	Location of cart release ↕ Time , speed
Question: How many stop watches do you need? Harry: probably one for each cart…we can do one and just do another for trial Adriano: one for each cart Leonardo: one for each Question: you were not able to see when I released the carts, how do you start time? Adriano: measure the time in between one hit and the other one hit	Location of cart release ↕ Time taken to travel each cart	Location of cart release ↕ Time difference of carts hitting	Location of cart release ↕ Time difference of carts hitting

Harry: yeah…that's right			
Question: discuss the error in the activity. A2... we assume that they go with the same velocity…we can tell but they don't really…because we didn't release them perfectly A1…friction A2…yeah... outside forces…that's we assume there like… I guess outside forces will be acting equally…like gravity will act like equally on both of them…	Source of Error ↕ Friction	Source of Error ↕ Gravity, external force	Source of Error ↕ Releasing carts
Direction of Explosion Bits			
Question: how do the explosion bits move Leonardo: I am assuming away from each other…action and reaction Harry: the only reason is that they would travel from like the center of it…like two bits traveling very much opposite to each other Adriano: …cause the explosion pushes each	Direction of explosion bits ↕ Push from the center of explosion	Direction of explosion bits ↕ Equal push in all direction	Direction of explosion bits ↕ Newton's third law Direction of explosion bits ↕ Symmetric nature of explosion

other equally in all directions…it is two Leonardo: that can be one particle here and one here…push equally at (points the center of the object) and that would be pushing equally… Adriano: yeah…it says explosion bits so we are assuming that whatever the bits are and whatever the explosion went off …they move opposite Harry: after the explosion they push together and two bits begin to move in…			
Question: Why not here or here and why at center of the line? Leonardo: because we assumed that they moved at the same velocity…with the same force Adriano: we are assuming that they are of the same…the bits of same mass… acted on by the same force and they should have the same velocity… Harry: we assume they			

were the parts of the same object… we assume force was same on both…both parts were of equal mass…			
Leonardo: whether it is at the center or closer to one side…back in the line or… Harry: so it is not determining that they hit exactly at the same time…so the time when the first one hit or which one hits first…(pause) so it will help us to determine how much off it was off center…so it would help us to determine how much off it was off center… Adriano: we are trying to find the distance from the two points …so it would be the end velocity and the time between the two parts…velocities of two parts Leonardo: it is the size…mass…velocity	Off center distance ↕ Time difference	Difference in distance ↕ End velocity	Shift from the center ↕ Mass, size, velocity

<table>
<tr><td>Harry: so basically what we do is… we basically transcribed the cart experience to the explosion bits …
Adriano: say that it is similar to these (refers to the lines drawn in the light activity)… each one would be like a set of carts…
Leonardo: cause we did not see inside (refer to light activity)</td><td>Explosion bits
↕
Collision carts</td><td>A line drawn in light activity
↕
A set of collision carts</td><td>Hidden explosion
↕
Hidden collision carts</td></tr>
<tr><td colspan="4">Gamma rays in Annihilation</td></tr>
<tr><td>Adriano: so how many gamma rays should be produced after they annihilate…to conserve the momentum
Harry: conservation of momentum
Leonardo: probably they are of same mass…that probably means something
Adriano: I guess it should be at least two…cause if the momentum before was zero…and if you had only one…it would have energy in one direction and that wouldn't be zero…</td><td>Number of Gamma rays
↕
Momentum conservation</td><td>Number of Gamma rays
↕
Conservation laws</td><td>Number of Gamma rays
↕
Mass of particles</td></tr>
</table>

Harry: opposite directions will cancel each other out…and the net would be still zero			
Question: what are the source of the energy of gamma rays Leonardo: it could be heat…that kinda like Harry: the annihilation…that's what is referred… Adriano: I thing like particle kinetic energy…their energy of motion would be transferred when they hit…	Energy of Gamma rays ↔ Annihilation of particles	Energy of Gamma rays ↔ Kinetic energy of particles	Energy of Gamma rays ↔ Heat of collision
Annihilation Location			

Question: describe the process of exact determination of the location of the process… Leonardo: it is pretty much like the…we did last time Adriano: carts… Harry: the circle thing Adriano: circle? Harry: we had a lot of lines…and there were area where it seemed to be concentrated… A2…I was thinking about the carts here it says describe the process to determine exact location of annihilation…just one annihilation A1…huh…just one annihilation… A2…that what I was thinking like…it senses where the gamma rays hit…draw the straight line between them A3…it senses which one hits first A2…it senses time between ‘em	Locating annihilation ↔ Light activity Annihilation region ↔ Region of lines intersection	One annihilation ↔ Cart activity Locating annihilation ↔ Cart activity Annihilation location ↔ Time between sensors	Locating annihilation ↔ First session activity

Appendix Q - An Example of Individual Interview Progression Diagram

Table Q.7.6: Motion of Carts

IDEA	Repel each other	It's a kinetic motion	Same distance in the opposite directions	Same amount of force supplied to each by magnets …they have the same weight
INPUT	What are they doing	Describe the motion	When release them perfectly what would happen	Conditions for equal speed

Heavier takes more force to move	Dealing with kinetic and potential energy
Why does heavy move slower	Physics ideas

Table Q.7.7: Location of Carts

IDEA	Released from this area since this one hit first	Cart over that end hits first	Figure out the velocity and distance	Need to take the time of release	(Long pause)
INPUT	Decide location of release	Assumptions made	Information to find exact location	I give you the velocity	You don't know when I released

10 cm that way	Can't think of the equation	Whichever one hits first and you measure the time in between	One
Speed of 10 cm/s…1 s time difference	Write the equation that is useful	How do you start the watch	How many watches

Table Q.3: Lights on Wall of the Cylinder

IDEA	First one was opposite to each other	Pair were closer and closer…the first pair started at the center of the cylinder…sends the lights opposite ends of the cylinder and go closer and closer to this side of the cylinder
INPUT	Any prediction	

Table Q.4: Central to Circle

IDEA	Center of the circle	Automatically I think…easier angle
INPUT	Where do you think that event might have taken place	Automatic think process

Table Q.5: Particle Direction

IDEA	From an explosion they propel opposite of each other	For every action there is equal and opposite reaction
INPUT	An object explodes into two parts…and the bits moves	Physics law involved

Table Q.6: Location of Explosion Along a Line

IDEA	Straight line…. from one point to the other	Equal distance from each point	It doesn't have to be at the center … not dealing with the time. Dealing with light so it may be at the center	Should be in the center…. because both light turn on at the same time
INPUT	Tell about the	Exact location	Why center of the line	(Provide mirror to see both lights turned on)

	location now			

Table Q.7: Pattern of Explosion Inside Cylinder

IDEA	Seems like this area…this areas …cause the lots of the lines are crossing there
INPUT	Additional information

Table Q.8: Cart vs. Light

IDEA	Can't measure intensity or time so there are sources of error and confusion in light	Easier to measure time and find location in cart	Something going in opposite directions at the same velocity… talking about light in light activity and about the object in cart	The different velocity in two cases
INPUT	Activity that gives better idea of event location		Similarities	Compare the activities

Equal and opposite reactions	Could figure out where it was depending upon how much time when it hits the edges
Physics concepts	Cart to light

Table Q.9: Number of Gamma rays in Annihilation

IDEA	At least one	Zero is not possible because it need to be detected in PET process … at least two gamma rays because sensors in the circle are in opposite …in collision two go in opposite directions find time difference and figure out where the collision took	They have the same velocity but in different directions so they cancel each other out to zero

		place	
INPUT	By one interaction at least how many gamma rays should be produced…they have equal speed when approach	Reason	When electron and positron meet what is momentum of system

I have no idea (long pause)	No…you need two …at least two	4, 6 and then 8 and so on
So at least how many gamma rays should be produced so that momentum is zero	Can we have zero momentum with one gamma ray	Next closest number

Table Q.10: Model Used in Gamma rays Direction

IDEA	It would go that direction and this would be along that direction at 180	They will bounce off each other going in opposite direction in the same line where they meet	Gamma rays go in all directions after electron positron mass are destroyed
INPUT	Draw the directions of the gamma rays	Two objects collide like this how will they move	Annihilation is not like collision of balls

Table Q.11: Sources of Gamma rays Energy

IDEA	Annihilation the source of gamma rays energy	Kinetic energy of electron positron	Energy from the attraction of opposite charges	E =m c2
INPUT	Sources of gamma rays energy			Well known equation about mass energy

				conversion

Table Q.12: Conservation Law in Annihilation

IDEA	Conservation of momentum and energy	Energy of electron and positron transfer to gamma ray	Conservation of charge
INPUT	Conservation laws involved		Any other law… how are electron and positron different

Table Q.13: Locating Annihilation

IDEA	It senses the gamma rays and processes the time from one sensor to get to the other and then uses the information	The speed of light… is gamma ray a light…or the speed of gamma rays	After one of them goes on…and then stops timing when another goes on…it gives the time it takes in between	Track activity last week the things that we did last time basically…cause obviously we can't cut and open and figure out where it is happening
INPUT	Describe process of exact determination of the annihilation location (picture of detector configuration provided)	What more information do we need	When does the machine start timing	What prompted you to think in that way

Table Q.14: Locating Abnormal Region

IDEA	Lighter area shows active area learned from science channel … more active means more collisions or happenings	The area of the tumor be where the lines intersect the most	Electron and positron approach this way and gamma rays move much in opposite direction…sensed more rays in this area which is more active region
INPUT	How will the machine tell that tumor is here	(Provide some drawing activities)… locate the tumor on it	What prompted to do in that way

Table Q.15: Influence of the First Session in the Second Session

IDEA	Easier to figure out something simple and something easier like collision, carts and lights coming out and use that to figure out how PET process works	Would take lot longer to put things together	Dealing with time and speed of light to determine the location
INPUT	First session helpful in second session	Had not done the activities earlier …what would be the difference	Common physics ideas in both session

Appendix R - An Example of Group Interview Progression Diagram

First row in the following tables corresponds to the ideas extracted from students' significant statements. The second row corresponds to the student label and the third row is the hints or questions provided to students at the corresponding step.

Table R.1: Motion of Carts

IDEA	Action and reaction on carts	Carts move in opposite directions	Equal speeds of carts	Heavier carts slower
STUDENT	A1	A2	A3	A1
INPUT	Carts repulsion			Unequal speed case

Different force and drag on carts	Momentum conservation in elastic collision	Momentum is continuous	Momentum a vector	Equal weight on both carts	Moving in opposite direction
A3	A2	A3	A1	A3	A1
				Momentum conservation in this process	Momentu m conservat ion

TableR.2: Location of Carts

IDEA	Carts are of same mass	Carts released at same time travel the same distance	Released near the side whichever cart hits first	Need to know length of the track, coefficient of friction	Normal force

STUDENT	A1	A2	A3	A2	A1
INPUT	Decide location of release		Anything can be added		

Timer	Two or three	Need two during hitting	Need to tell when released	Find time difference when they hit, need one watch
A3	A3	A2	A3	A1
	How many timer			You can't see when and where I released

Measured the time difference between two carts hitting	Velocity of carts	One of them hit 0.4 s earlier	It traveled about 5 cm during that time	Five cm from center of track
A1	A1	A3	A 1	A 2
What is the time you recorded	What more information needed to find location	Velocity is 15cm/s		

That's the difference in time	It is the time both carts traveled	It is time lapse…need to deduct the	Total distance 90 cm is traveled in	One of the carts traveling 0.31 s longer than the

		length	0.31 s	other
A3	A2	A1	A2	A1

How to find each one to travel	One traveled 55 and another 65cm
A2	A1

Table R.3: Lights on the Walls of the Container

IDEA	Lights opposite to each other	Lights are close to each other	They were further away and then closer	Thought that they were opposite to each other from the closest separation	Change of distance every time…ran dom
STUDE NT	A1	A1	A3	A1	A2
INPUT	Any pattern			Any prediction	

Table R.4: Center to the Circle

IDEA	Anywhere	From the center of circle	Along a line joining lights	Automatic thought process that …angles and lengths are easier from center
STUDENT	A2	A3	A1	A3

INPUT	Where the bits started			Reason to start at center

Table R.5: Particle Direction

IDEA	Equally divided parts move with equal speeds	Different force to different masses	Force on two bits depend on their size	They move in straight line
STUDENT	A1	A1	A3	A1
INPUT	An object explodes into two parts…and the bits moves	If masses are unequal		

Table R.6: Explosion along a Line

IDEA	Explosion in middle of line	Why not anywhere inside the circle	They are two pieces	Thought about continuous emission of light by explosion	Just two pieces come out	They explode in opposite direction	Same force on both	Equal and opposite reaction
STUDENT	A3	A2	A1	A2	A1	A3	A1	A3
INPUT	Location of explosion		Can you explain to him (A2)	Something else explodes giving the lights				

Don't know which one	Light at the same time	Need to see intensity	Need to do same thing as cart seeing which hits first
A3	A1	A2	A3

Closer to one side because of the brightness of light	Intensity tells more about the energy than the location…need stop watch to measure time between two light hitting	Possible theoretically	Need length between light positions…speed of light	Time
A2	A1	A3	A1	A3
			Anything that is necessary to ascertain the location	

Table R.7: Pattern of Explosion Inside the Cylinder

IDEA	Can just tell about one event form one line	Multiple events in the region of intersection	Region of intersection	Approximately at the center of circle
STUDENT	A3	A1	A2	A3
INPUT	Complete locating different events	Additional information		

Table R.8: Cart VS. Light

IDEA	Cart was good to start with	Accurate idea in cart by doing accurate measurements	Can't measure time in light activity	Objects moving in opposite direction	Multiple occurrence in light activity	Newton's laws involved	Going opposite direction	Conservation of momentum	See the things in cart and use that idea in light	Cart a good introductory activity to help understand light
STUDENT	A1	A3	A2	A2	A1	A1	A3	A1	A1	A3
INPUT	Activity that gives better idea of event location			Compare the activities		Physics concepts			Ideas of cart in light	

Table R.9: Number of Gamma rays

IDEA	Like the last activity when they annihilate it splits into two directions so that momentum is zero	One electron and one positron…so two gamma rays
STUDENT	A1	A2
INPUT	The least number to conserve momentum (initial momentum was zero)	Next closest number

Table R.10: Model in Gamma ray Direction

IDEA	Gamma rays go opposite to each other	Heading in equal and opposite direction	No preferential direction	Force comes that way…like carts they bounce back with same speed
STUDENT	A2	A1	A3	A1
INPUT	Path of the gamma rays		Preferential direction	

Table R.11: Sources of Gamma ray Energy

IDEA	Electron positron collision… momentum of particles	Momentum was zero just before they meet… convert mass into energy	Kinetic energy	Einstein's equation	It changes into wave	Change into different form…gamma rays…light	Gamma rays is electromagnetic radiation… same thing as light
STUDENT	A3	A2	A1	A2	A3	A1	A2
INPUT	Sources of gamma rays energy						

Table R.12: Locating Annihilation

IDEA	Positron strike normally and gamma rays go horizontally	Detector configuration similar to light activity…	Light received by outside of the cylinder and then construct the location	Draw a straight line between the detectors receiving gamma rays to find exact location	Confused on how positron come…beta activity	Detectors pick gamma rays	Can't be sure since tissue amount is not known	Location dependent on tissue	Tissue is mentioned in worksheet	It is same thing like cart…using the idea of time hitting cart	Coincidence circuit knows the difference in time	Distance between the detectors	Speed of gamma rays
STUDENT	A2	A3	A1	A3	A2	A2	A1	A3	A1				
INPUT	Describe the process of determination of the annihilation location					Concentrate on process							

different…not sure if that difference can be known in this case			
A2	A1	A1	A2
Just one event…this picture (picture in problem) tells that this detector picks one gamma rays and this pick one gamma ray… describe the process…		What more information do you need	

Table R.13: Locating Abnormal Region

IDEA	More gamma rays emitted from the abnormal region	See where the most intersection occurs	It is close to the circle thing the other day
STUDENT	A2	A1	A2
INPUT	Finding the region		

Table R.14: Role of the First Session in the Second Session

IDEA	Would not be able to understand concentration things if not done the first session	Lights in straight line helped understand drawing activities…electron positron collision relates to explosion and the reason of gamma ray direction known from the light activity	Big concrete model of cart used to understand what positron do and how gamma rays move
STUDENT	A3	A2	A1

INPUT	First session helpful in second session		

Activity build foundation to jump to gamma rays and PET	To determine the signal location	Would take lot longer	Couldn't know if the gamma rays move opposite	Doing hands on and then looking at paper helps to get sense of how something works
A1	A2	A3	A1	A2
	Where was cart activity most useful today	Had not the activities earlier this week…what would be the difference		

Appendix S - Teaching Unit of PET

EXPLORATION

Locating hidden events is widespread experiments in physics. Such technique is very popular in modern technologies such as medical imaging. An example is positron emission tomography where the investigation of function of brain and other organs is possible without doing surgery. To learn the PET imaging technique you will first explore with some hands-on activities. The activities below will guide you to think about the process of determination of hidden events that will help you to understand some of the key processes involved in the PET technology.

ACTIVITY 1:

On your table you have two low friction carts on the track. In this activity you will be exploring the behavior of the motion of the carts. Please write your observation and your opinion in response to questions 1-3 below before you discuss with your group partners. Once all of you complete writing your responses compare and discuss to try to come up with consensus.

1. Bring the carts close to each other and release them. Describe the motion and compare the speeds?

2. Measure the speed of the carts. If you have two carts in the similar situation of motion when do the carts have equal speed and when do they have different speeds?

3. Discuss the physics laws that explain the behavior of motion of carts.

Now cover the track with the barrier such that some of you sitting to the next side of the barrier can see only two ends of the track. One of you will release two carts somewhere from the hidden part of the track and rest of you need to explore to find a way to locate the place of origin of the carts. Now, you need to respond to questions 4-6 below before you discuss with your group partners. After writing your responses compare and discuss with your partners to try to come up with consensus in each of the questions.

4. What assumptions did you make to find the location where the carts were released?

5. What measurements would you need to do to find the location?

6. What are the major factors that cause uncertainty in your prediction of location?

ACTIVITY 2:

At your table you see a cylindrical enclosure. An explosion is triggered when you turn the switch on. When you rotate the switch you will trigger a series of explosions. The explosion bits move and as a result you see the lights on the wall of the cylinder. Your main goal is to explore with this activity to find the location of such explosion events taking place inside the cylinder. Please write your personal response to questions 1-5 and then discuss with your partners. Also put the answer after you reach to the consensus.

1. Rotate the switch and observe the lights on the wall of the cylinder. Explain if you observed any trend of the light positions.

2. Concentrate on only one explosion event. Locate on a sheet of paper the positions where you saw the lights on the wall of the cylinder. Draw the paths of the explosion bits so that they get to the locations where you saw the lights.

3. Describe the reasons for your drawing.

4. What information does your drawing provide about the location of the explosion?

5. What measurements would help you to locate this particular explosion event?

Now, you need to record all the light pairs in the provided sheet of paper. Please do not forget to label the pairs. After completing the drawing respond to the following questions. Once again discuss to reach the consensus afterwards.

6. Draw the paths of explosion bits of every event. What did you consider regarding the directions while drawing the paths?

7. What additional information about the locations of events did you get after completing this drawing?

CONCEPT INTRODUCTION

You interacted with two activities that were common in many aspects. The determination of hidden location by working backward was the main idea. The main physics idea involved in both the process was momentum conservation. The carts were at rest initially before they were released. So, the momentum of the carts system was zero. Once you released the carts they are moving in opposite direction to keep momentum of the system zero. Thus, if the carts are of equal mass they should have equal speed but in opposite directions. The same idea holds in the light activity. An object at rest explodes into two parts in order to conserve the momentum the bits must move in opposite direction with equal and opposite momentum.

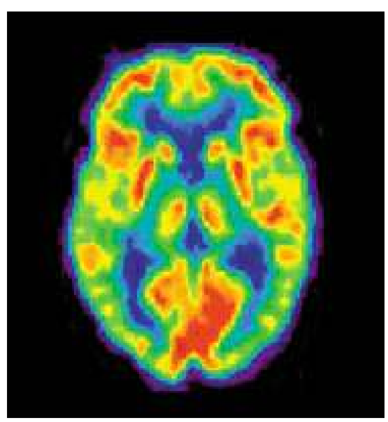
The equation useful for the quantitative determination of location in each cases is $d=vt$. Where 'v' is the speed of each carts in the cart activity and that of bits that travel in the light activity. Similarly, 't' is difference of time between two carts hitting the ends in the cart activity and that of two lights hitting the wall of the cylinder in the light activity. The difference of the distance traveled by one as compared to the other is given by 'd'. To find the numerical value of the event location you need to know the length of track and length of the carts in the cart activity while in the light activity you need to know the distance between the two light spots.

The main difference between the two activities is that the cart activity is 1-dimensional problem whereas the light activity involves 2-dimesions. You could measure time difference of two carts hitting in the cart activity easily that is why you could tell the exact location for each events. Whereas in the light activity you could not measure the time difference of two lights hitting on the wall and therefore could not predict the exact location for a particular event. However, you ran through series of observations and plotted them in the sheet of graph paper to point out the common region of explosion events.

CONCEPT APPLICATION

The following picture shows a positron emission tomography (PET) scan of brain. Positron Emission Tomography (PET) is a medical imaging technique used to detect changes in the cellular function of internal organs or tissues without doing surgery. The physiological changes in the cellular function are pictured that enables to diagnose certain diseases at their earliest stages.

Figure S.7.29: A PET scan



A drug possessing a special type of atom is administered to the patient by injection which localizes in the region of the abnormal tissue or organ. After 30-40 minutes of the injection the patient is taken to the scanner. The scanner has a ring of detectors that goes around the patient's body that is under investigation. A positron, which is a positively charged particle having equal mass and equal magnitude of charge as that of an electron, is emitted by the atom by the process of beta activity. The positron then travels a short distance before finding an electron on the path.

Just before they meet the momentum of the electron-positron system can be taken as zero. After they meet the annihilation takes place resulting in the conversion of electron-positron mass into gamma ray energy. The PET scanner detects and records the emitted gamma ray signals. The computer processes signals and construct the image of the organ or tissue under investigation.

The above discussion gives you the overview of the positron emission tomography technique. Now you are going to understand the mechanism and key ideas behind this. Let us discuss the product of electron-positron annihilation. You need to write the answers in response to questions 1-3 individually and then discuss. Write the answer after you reached to the consensus also.

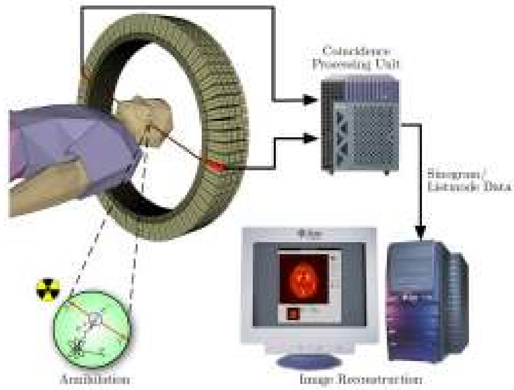
1. Considering the energy and momentum conservation state the least number of gamma rays produced by an event of electron-positron annihilation.

2. Continue on question 1 to draw the path of gamma ray or rays produced after the annihilation process.

3. Discuss the conservation laws involved in the electron-positron annihilation.

Now you are going to learn the image construction process in PET. Figure below shows a spot where annihilation is taking place. The annihilation location is inside the head which is not visible externally. The machine figures out such annihilation spots and eventually creates images of the tissue. So the most important function of the machine is to determine the exact locations of many such annihilations.

Figure S.7.30: Annihilation Location



Write your responses to the questions 4-6 working independently and discuss to try to come up with an agreement.

4. Consider only one annihilation event and refer to the above diagram to describe the process to determine the location of the annihilation.

5. What information would you need to know to find the exact location of the event?

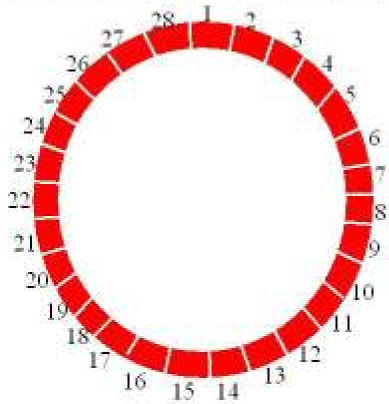
6. How does the PET machine ascertain the abnormal region in the tissue or organ?

The following activities will help you to think about the image construction process in PET. After doing the activities you will learn how a PET scanner construct image of abnormal region of tissue.

The detector ring and the data are provided in Figure S.7.31. You need to indicate the probable region of abnormality.

Figure S.7.31: Image Construction

Annihilations	A	B	C	D	E	F	G	H	I	J	K	L
Detectors	1,11	2,13	3,15	4,16	5,20	6,22	7,24	8,25	9,26	10,28	12,23	14,19



Also respond to the following questions and discuss with your partners.

7. Give the reasons that support your drawing.
8. What are the bases that the tumor might be in the region that you pointed out?

In the Figure S.7.32 you are provided a detector configuration and an abnormal region of tissue (green part). Draw how the annihilations are detected.

Figure S. 7.32: Annihilation Detection

Also respond to the following questions.

9. Discuss the reason of your drawing.

10. Compare the activities related to Figure S.7.31 and S.7.32.