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"A study about how students are able to analyze mechanics situation using Newton's laws"

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" A study about how students are able to analyze mechanics situation using Newton´s laws"

Presentada por el alumno:

Seyed	Fadaei	Azita
Apellido	Apellido materno	Nombre(s)

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aspirante de:

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The students who participate in this study.

Dedication

To my parents (Seyed Mohammad and Roghayeh)

Abstract

To help students recognize their abilities to understand the environment, it needs to engage students in appropriate activities, and also, to help us to find ways to assess students' performance by formative assessment activities. This work focuses on comparing two methods of teaching to achieve a better understanding of the environment through Newton's laws. We show a methodological proposal based on Active Learning Physics supported by Interactive Conceptual Instruction (ICI) methodology, which is designed to promote collaborative learning in high school students. We begin by planning activities in physics functions as one of the ways of representing physical ideas, especially in force and motion. Then applying them in our teaching method, comparing traditional teaching process. These processes involve observing, finding patterns, building and testing explanations of the patterns, and using multiple representations to reason about physical phenomena. The sample for this study consisted of 41 secondary girls students in Somayeh High school in the region 5 of Tehran, Iran. The sample was randomly selected from second year student (16 years old girls) undertaking an introductory physics course and the sample were randomly divided into a control group (Traditional, N=20), experimental group (MRA [Multiple Representation Activities], N=21). These students took Mechanics for the first time in their physics courses at high school. The course consists of two seventy-minute lecture sections per week for regular teaching and for applying MRA in experimental group, 20 minutes per week is added as an extra class. The independent variables are two different methods of performing teaching these are divided into Traditional and Active Learning (based on a package of activities, that consist in demonstrations, videos, worksheets) and ICI (teaching methodology). The Dependent Variable in this study are the conceptual learning of Newton's Laws and the skill form these we will explore the changes in these two domains separately for each group before and after the study's treatments and compare them with each other. To evaluate the effect of the Active Learning on students' learning, FCI (Force Concept Inventory) is used. Analysis response of activities mentioned show that maturities in students' analysis are increasing. For analysis data we use Hgain and Dgain and Dloss and Retention Factor, which allow obtain an analysis with more detail in conceptual improvement that students have starting the course and can show advances reach in their reasoning at the end of instruction. These factors allow obtain charts which are labeled depending on the score and the FCI items reached in each question, and allow view students' Hgain, Dgain, Dloss and Retention changes in each group. Results show significant advances in experimental group so the conceptual learning in Newtons' Laws that conducts students to analyze Mechanics situations with the help of Multiple Representation Activities and Interactive Conceptual Instruction is more possible than the last.

Resumen

Con el fin de ayudar a los estudiantes a reconocer sus capacidades para comprender el entorno, es necesario involucrar a los estudiantes en actividades apropiadas, y para encontrar varias maneras de evaluar el desempeño de los estudiantes por las actividades de evaluación formativa. Este trabajo se centra en la comparación de dos métodos de enseñanza para lograr una mejor comprensión del medio ambiente a través de las leyes de Newton. Mostramos una propuesta metodológica basada en la física de *Aprendizaje Activo* con el apoyo de la metodología de la *Instrucción Conceptual Interactiva* (de siglas en inglés: ICI), que está diseñado para promover el *Aprendizaje Colaborativo* en los estudiantes de secundaria. Comenzamos por las actividades de planificación en las funciones físicas como una de las formas de representar las ideas físicas, sobre todo en la fuerza y el movimiento. Entonces las aplicamos en nuestro método de enseñanza, comparando contra el proceso de Enseñanza Tradicional. Estos procesos implican la observación, la búsqueda de patrones, la construcción y la prueba de las explicaciones de los patrones, y el uso de múltiples representaciones para razonar sobre los fenómenos físicos. La muestra para este estudio consistió en 41 niñas que son estudiantes de secundaria en la escuela secundaria de Somayeh en la región 5 de Teherán, Irán. La muestra fue seleccionada al azar de un grupo de estudiantes de segundo año (niñas de 16 años) donde se hizo la realización de un curso de introducción a la física y las personas de la muestra, se dividieron al azar, en un grupo de control (con Enseñanza Tradicional, N=20), y un grupo experimental (con MRA [Actividades de Representación Múltiple], N=21). Estos estudiantes tomaron Mecánica por primera vez en sus cursos de física en la escuela secundaria. El curso consta de dos secciones de conferencias con setenta minutos por semana, para la enseñanza regular y para la aplicación de la ERM en el grupo experimental. Después, 20 minutos por semana se agregan como una clase extra. Las variables independientes son dos métodos diferentes para llevar a cabo el método de enseñanza que se divide en el Aprendizaje Tradicional y el Aprendizaje Activo (con base en un conjunto de actividades, que consisten en demostraciones, videos y hojas de cálculo) y la metodología de enseñanza llamada *Instrucción Conceptual Interactiva* o ICI. La variable dependiente en este estudio son el aprendizaje conceptual de las leyes de Newton y la habilidad que vamos a explorar es en base a los cambios en estos dos dominios por separado para cada uno de los grupos antes y después de los tratamientos del estudio y compararlos entre sí. Para evaluar el efecto del Aprendizaje Activo en el aprendizaje de los estudiantes, se utiliza el FCI (siglas en inglés de *Inventario de Conceptos de Fuerza*). El análisis en la respuesta de las actividades ya mencionadas, demuestra que la maduración de los conceptos de los estudiantes está en aumento. Para el análisis de datos utilizamos a Hgain y Dgain y Dloss y el factor de retención, que permite obtener un análisis con más detalle en la mejora conceptual de los estudiantes que han comenzado el curso y podemos mostrar avances en el alcance de su razonamiento, al final de la instrucción. Estos factores permiten obtener gráficos en los que se etiquetan la puntuación, dependiendo de los conceptos de FCI que obtengan en cada pregunta, y permiten ver la Hgain, Dgain, Dloss, de cada estudiante y los cambios de retención en cada grupo. Los resultados muestran avances significativos en el grupo experimental, así que el aprendizaje conceptual en las Leyes de Newton que conduce a los estudiantes a analizar la Mecánica es más posible que se de bien en la práctica, gracias a la ayuda de la *representación múltiple* y las actividades de la *Instrucción Conceptual Interactiva* (ICI), que a la Enseñanza Tradicional.

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Introduction

Students in introductory physics courses often have difficulty gaining a robust understanding of common physical laws. A student develops an understanding of how the world works well before he or she enters a classroom. This student's existing model of how things work affects what he or she can learn from a physics class. McDermott[1], Redish[2] note that the student's mind is not a "blank slate." Students arrive in physics classes with notions, ideas, and models in their minds. Learning does not simply mean the acquisition of a new batch of rules and ideas; it also involves reconciling this new information with the students' pre-existing ideas. To teach students effectively, it is important to first understand what those existing ideas are. This constructivist epistemology provides a basis for understanding why students often have difficulties with physics topics.

Teaching physics for understanding is a complex issue. It involves learning the macroscopic properties of phenomena, explaining the macroscopic phenomena and processes using models, using symbols in mathematical problem solving, and understanding the processes that scientists use in inquiry.[3]To understand a concept in physics explaining the macroscopic phenomena and using models and different presentation have a main role. Many studies in PER suggest that Newtonian mechanics is perhaps the most extreme example of difficulties in teaching physics at the high school. These difficulties are mostly attributed to misunderstanding of specialized teaching method. Active learning method often assigns new understanding to everyday terms used to describe physics and it is clear that understanding physics laws can help to explain everyday real life and macroscopic phenomena. Analyzing mechanics situation as a macroscopic phenomenon using Newton's Laws is a way to investigate students' understanding of Newton's Laws. Although it depends on modeling and representation methods. The most effective way to identify if a student's understanding of a concept is robust is to use multiple representations whenever possible. This is examined for some of the Newton's Laws learning activities.[4]

In this dissertation we present an approach to analyzing of the role of activities and representations in investigating Newton's Laws in Mechanics situations. We try to plan some learning activities depends on representation methods, which help students to analyze mechanics situations using Newton's Laws. The data are investigated using FCI tool. Specifically, we combine the idea of ICI (Interactive Conceptual Instruction) methodology and activities from ISLE (Investigative Science Learning Environment) to build a teaching approach that accounts for the role and function that teaching method serves for teachers.

The research question and objectives are as follow:

Research question

- How do the multiple representation activities (MRA) in teaching Newton's Laws (NL) affect students' ability to analyze mechanics situation?

General objective and particular

General objective:

- Improving the students' ability to investigate mechanics situation, using Newton's laws.

Particular objectives:

- Designing activities based on multiple representations in Mechanics situations.
- Study the effectiveness of multiple representation activities on the students' conceptual learning in Newton's laws.

The aim of the present study is to determine student levels of understandings about Newton's Laws of motion and to identify student models that underlie and inform those understandings.

In summery the results of this analysis show that teaching method and learning activities are very important in learning Newton's Laws and analyzing mechanics situation in real world.

The dissertation is organized in the following way:

In Chapter 1, I will provide a brief introduction to the broad issues of learning Newton's laws. I will explain why analyzing Mechanics situation is important in the broader context of representations of Mechanics knowledge.

In Chapter 2, I will try to draw the formative activities and assessments are built on ISLE (Investigative Science Learning Environment) environment. ISLE is a comprehensive learning system that provides a general philosophy and specific activities that can be used in "lectures" (interactive meetings where students construct and test ideas), recitations (where students learn to represent them in multiple ways while solving problems) and labs.

Also teaching methodology is the subject of chapter 3. This research is about planning and using some activities for undergraduate students in level 10 in High school to teach Newton Laws .The research focuses on ICI (Interactive Conceptual Instruction) methodology for teaching Newton Laws based on formative assessments from ISLE environment, and we will present the teaching approach (which we refer to as Interactive Conceptual Instruction, ICI) was developed to promote conceptual understanding of the force concept and was based on the premise that developing an understanding of mechanics requires an interactive process in which there is opportunity for ideas to be talked through, and thought through, between teacher and students. This chapter outlines the research design, timeline, background and participants, teaching strategy, instruments used for collecting data, data analysis of the study.

Testing the idea and presenting the data on which it was constructed, is the goal of Chapter 4. The diagnostic tool is FCI (Force Concept Inventory).I will use the analysis to show how focusing on the Force Concept Inventory, a multiple-choice test was used to analyze students understanding in Newton's laws. I will present results for two groups of students that can be explained with the analyzing data. This will be done entirely in the field of Newton's Laws in mechanics. In addition I will state the definitions of Hgain, Dgain, Dloss, and Retention in analyzing results.

Chapter 5 is the concluding chapter. I will show how the activities presented in Chapter 2 successfully make an improvement in understanding Newton's laws and analyzing mechanics situation. This means that we can understand our students' learning processes by doing and analyzing MRA (multiple representation activities).

Chapter 1
Theoretical Framework

In this chapter, I will provide a brief introduction to the incorrect ideas about the Newtonian world and failure of physics conceptual teaching in Newton's Laws. In addition I will explain students' conceptual difficulties in understanding force and Newton's Laws and the role of multiple representations in teaching Newton's Laws to investigate mechanics situations.

The purpose of thesis is to show the benefits of using active learning (MRA activities and ICI teaching strategy) in conceptual understanding of Newton's Laws. We propose that using this active learning package could improve and develop students' abilities to analyze mechanics situation using Newton's Laws. There are some published researches on student concepts of Newton's Laws. The researches in most cases have focused on pre-college students, from young children to high-school students. In most of these researches, there is an emphasis on uncovering and identifying student misconceptions, though not necessarily exploring the prevalence of these misconceptions. A number of studies have been performed to gain a better understanding of how students think about Newton's Laws. We focus on researches about the main concept of Newton's Laws: force and motion especially in high school.

1.1. Incorrect Ideas about the Newtonian World

The great game of science is modeling the real world, and each scientific theory lays down a system of rules for playing the game. The object of the game is to construct valid models of real objects and processes (Hestenes, 1992). Such models comprise the core of scientific knowledge. To understand science is to know how scientific models are constructed and validated. The main objective of science instruction should therefore be to teach the modeling game. If modeling is the name of the game it should be no surprise, considering the typical textbook, that students are perplexed and confounded by introductory physics. Students are left to extract the rules of the game for themselves from a torrent of details. That is akin to learning chess simply by watching the chessboard pieces mysteriously disappearing and reappearing on the board, strange anomalies like castling, sudden terminations of play! The game is hard enough to fathom after you know the rules. No wonder that few students get the rules straight while the majority misses the point of the game entirely. Most students think the game is to collect and memorize facts. This blinds them to the beautiful structure of the Physical World revealed by science.

Newtonian theory, like every other scientific theory, defines a Conceptual World. This world is populated with conceptual models of real objects and processes in the Physical World. A sharp distinction should be maintained between the Newtonian World and the Physical World it characterizes. Many students and textbooks fail to do this. Consequently, it is widely believed that Newton's Laws are inherent in the Physical World (Hestenes, 1992), just waiting to be discovered, like Columbus discovered America. On the contrary, as Einstein repeatedly emphasized, the laws of physics are "free creations of the human mind". Newton's Laws were invented to describe certain regularities in the motions of real objects. These regularities are, indeed, inherent in nature, but they could not be discovered without the invention of adequate concepts to describe them. It is no accident that they were not discovered before the "Age of Newton", though they had always been on display in "the Book of Nature" for everyone to see. The very conception of "Newton's Laws" would not have been possible without a sequence of prior conceptual inventions, including the inventions of (1) Euclidean geometry, which defines the concept of space, (2) the concept of acceleration, first employed by Galileo in the analysis of motion, (3) analytic geometry, invented by Descartes to represent geometric curves by algebraic equations, and (4) differential calculus, the mathematical invention of Newton and Leibniz which proved to be essential not only for formulating Newton's laws but for applying them as well (Hestenes, 1992).One moral of all this is that conceptual invention and empirical discovery go hand-in-hand. One cannot discover what one cannot conceive. Likewise, students must become familiar with the Newtonian World before they can recognize reflections of the Physical World within it and use it as a conceptual tool for understanding the Physical World. It follows that a primary objective of introductory physics should be to help students enter the Newtonian World. Actually, the Newtonian World must enter the student, for it is a conceptual world which must be recreated in the mind of anyone who would know it. Each student must literally reinvent the Newtonian World in his/her own mind to understand it. That is a creative act of high order, so it is no wonder that students find it difficult, especially considering the fragmentary presentation of Newtonian theory in the textbooks.

Newtonian theory defines the Newtonian World, but it was never spelled out completely by Newton, and it has been greatly refined and extended by physicists since (Hestenes, 1992). For these reasons, a pious invocation of Newton's three laws of motion is an inadequate formulation of Newtonian theory, though it is standard textbook practice. Educational research has established that most students can recite these laws but few understand them. It is high time that this textbook tradition be broken and replaced by a sharp, compact, coherent and complete reformulation of Newtonian theory, if only to specify precisely what students must learn and so guide instructional design (Hestenes, 1992).Results from research on student understanding in physics indicate that certain incorrect ideas about the physical world are common among students of a wide variety of national backgrounds, educational levels and ages. Effective learning of concepts and laws, constituting the basis of physics, is essential for understanding and explaining natural phenomena. In fact students can apply an understanding of how physics works to their everyday life. Using Newton's Laws to analyze mechanics situation is a way to measure students' conceptual understanding in learning mechanics.

1.2. Failure of Science Teaching

Newtonian mechanics is perhaps the most extreme example of the failure of science teaching at the high school and beginning college level evidently because (1) Newton's laws violate common-sense interpretation of everyday experience, and (2) understanding of the laws requires relatively advanced thinking processes that some associate with the formal operational level .Progress toward a solution of this extreme-case problem would be a hopeful sign for eventual improvement of science instruction generally(Hake,1987).

Newton’s Laws of motion have been included in primary, secondary and university curricula and play a fundamental role in explaining real life physical phenomena. The existence of alternative models to explain Newton’s Law of motion is attributed to weaknesses in teaching processes. Consequently, such weaknesses will be perpetuated and therefore play an important role in preparing and implementing future teaching activities, and will adversely affect the learning of future generations of students. Students’ levels of understanding of Newton’s Laws of motion showed significant weaknesses in fundamental knowledge, particularly in providing scientific explanations. This result is consistent with previous research focusing on student misconceptions about Newton’s Laws of motion. This lack of understanding can be attributed to the inability of students to relate scientific knowledge with real life phenomena and experiences. It suggests that the lack of real life examples in curricula experienced by students could be a significant factor contributing to their lack of understanding (Çelenk and Demirtas, 2013).There is considerable evidence that university students often have many of the same conceptual and reasoning difficulties that are common among younger students. There is often little change in conceptual understanding before and after formal instruction. Moreover, students are often unable to apply the concepts that they have studied to the task of solving quantitative problems, which is the usual measure for student achievement in a mechanics course. Results from research have repeatedly demonstrated that students often emerge from introductory physics courses with many of the same incorrect beliefs that have been found to be prevalent before instruction.

1.3. Students' Conceptual Difficulties in Understanding Force and Newton's Laws

Mechanics is probably the area of physics that is best studied by physics education researchers. There are many papers published which document students’ difficulties and present examples of “typical” student responses in interviews.

Force is the central concept of Newtonian mechanics. Studies show that physics students have an alternative concept of force and individual students consistently applied alternate concepts of force in different contexts. For some of the forces; students did not identify the effect of the force on the relevant receiver. The task of drawing force diagrams did not cause any particular difficulties. Students’ difficulties with gravity concerned the effects of the force on the motion of a falling object, rather than the nature of interaction itself. However the support force was introduced, necessarily requiring consideration of balanced forces, considerable difficulties became apparent. Few students provided correct examples of balanced forces, and even those who did were rarely consistently correct in all the situations they selected. Many experience demonstrates that developing a meaning for the word ”force” that is congruent with the physicist's meaning is a far from easy task for students.

Simple lecture demonstrations were shown to several hundred first-year university students in Australia. The students exhibited a strong tendency to observe their prediction regardless of what actually happened. The results of this study indicate that many students believe that motion implies a force, both before and after the study of introductory mechanics.

The test consisted of questions about the forces acting on various objects such as a book at rest on a table, a pendulum bob, a cannonball in flight, etc. For questions concerning objects in motion, the authors found that students who included force acting in the direction of motion only included this force in some situations. The belief that no forces act on an object at rest was prevalent (Clement, 1982). Many students believe that a constant force is required to sustain constant rate motion and that when the force is removed, the object stops moving. Many of these researchers have noted a similarity between students' naive models of force and motion and historical models developed by the ancient Greeks or early physicists such as Galileo and Newton (Brookes and Etkina, 2009).In other research the students demonstrated a strong tendency to assume a direct linear relationship between force and velocity (Viennot, 1979).

Some frameworks are constructed for identifying the state of student understanding of the laws of mechanics and explore the dynamics of how student views develop through instruction (Thornton, 1997). Many non-Newtonian ideas were observed, including: a constant force produces constant velocity and in the absence of forces, objects are either at rest or slowing down (Champagne and Anderson, 1980). University students, many of whom had studied physics, were asked to predict the motions of objects moving in constrained curved paths. Many believed that an object would "remember" the curve after it left the constraint (McCloskey and Caramazza and Green, 1980). More than 100 university students with different backgrounds in physics were asked to compare the forces that two interacting objects exerted on each other. About two thirds thought that they would be of different magnitude in some circumstances. Passive objects don't exert forces (Brookes, 2006). The investigators examined the beliefs about Newton's third law of 100 university students before instruction. Half of the students were given a handout describing forces with explicit statements of the third law. No student without the handout applied the third law correctly and of those with the handout, fewer than half applied it correctly (Boyle and D. P. Maloney, 1991).

Clement (1982) stated that when the concept of force is misunderstood at the qualitative level it is called a "conceptual primitive". He states that the source of this qualitative misunderstanding can be traced to a deep-seated preconception that makes a full understanding of Newton's first and second laws very difficult. Robertson, Gallagher and Miller (2004) argued that one of the most basic concepts related to force and motion is Newton's first law. They investigated student understandings of Newton's first law across a range of ages. They used a set of inquiry-based activities designed to help students understand the reasoning behind Newton's first law. Newton's laws are important because they have easily visible applications in the daily lives of students. McCarthy (2005) demonstrated how Newton's first law of motion applied to the everyday lives of students. He developed a learning cycle consisting of a series of activities to teach the concept of inertia. O'Shea (2004) demonstrated the action of Newton's second law by describing the forces involved during snowboard jumping, while Smith and Wittman (2007) developed three tutorials designed to improve student understandings of Newton's third law. Newton's third law is frequently presented several pages after the first law , and it may be either implied or explicitly stated that it is relevant interacting objects in isolated systems or , more restrictively , to understanding collisions and explosions. Newton's first and third laws are intertwined: one cannot be understood without the other (Arslan and Devecioglu, 2010).

1.4. The Role of Representation

In order to improve education, one needs to understand what is happening in the classroom. In particular, what are students doing and learning when they learn physics? One answer is that students are engaged in learning or constructing the concepts of physics and changing their prior conceptions about how the world works (Sessa and Sherin, 1998). Physics education research has devoted a great deal of energy and attention to the question of how to help students learn/construct the concepts of physics faster/better and the difficulties that students have in changing their prior conceptions (Posner and Strike and Hewson and Gertzog, 1982). Perhaps the most serious difficulty that has been identified is failure to integrate related concepts into a coherent framework. The primary activity that students encounter and participate in, in a physics course, is representing (Lemke, 2001). Rote use of formulas is common. To solve standard problems, mathematical manipulation may suffice. To be able to apply a concept in a variety of contexts, however, students must not only be able to define that concept but also relate it to others. They also need to differentiate that concept from related concepts. Traditional instruction does not challenge but tends to reinforce a perception of physics as a collection of facts and formulas. Students often do not recognize the critical role of reasoning in physics, nor do they understand what constitutes an explanation. They need practice in solving qualitative problems and in explaining their reasoning. Students are often unable to relate the concepts and formal representations of physics to one another and to the real world. An inability to interpret equations, diagrams and graphs underlies many conceptual and reasoning difficulties. Also they have difficulty with: algebraic representations, diagrammatic representations and graphical representations (McDermott, 1993). Multiple representations facilitate the relation between concepts of physics to the real world and stand for, depict, symbolize or represent objects and/or processes. Some examples of multiple representations in physics include words, diagrams, equations, graphs, and sketches. The positive role of multiple representations in student learning has been suggested by many educators. Finding facilitating representations for almost any class of problem(s) should be seen as a major intellectual achievement, one that is often greatly underestimated as a significant part of both problem solving efforts in science and efforts in instructional design. Multiple representations have many benefits:

• Multiple Intelligences; students learn in different ways. Different representations are compatible with different learning styles.

• Visualization for the brain; physical quantities and concepts can often be visualized and understood better using concrete representations.

• Help construct another type of representation; some concrete representations help in constructing a more abstract (often mathematical) representation.

• Some representations are useful for qualitative reasoning; qualitative reasoning is often assisted by using a concrete representation.

• Abstract math representations are used for quantitative reasoning; a mathematical representation can be used to find a quantitative answer to a problem.

To use multiple representation in this research ; first of all we identify key components and use a key physics concept to know what those concepts are and how students can benefit from the representations. After that we construct other representations; with a key concept in mind, we can create another type of representation focusing on that same concept. Then we use them in the classroom; 1. Formative assessment

(a) Give one representation, have students create another.

(b) Give two or more representations, have students check for consistency between them.

(c) Give one representation, have students choose a second consistent one from multiple choices.

2. Summative assessment; these representations can be used as an alternative to traditional test questions using the methods described above. Some types of representations are:

• Verbal descriptions

• Pictures

• Graphs

• Mathematical

• Motion diagrams

• Free body diagrams

• Energy bar charts

• Momentum bar charts

• Field line diagrams

• Electrical circuit diagrams

• Ray diagrams

• Wave front diagrams

• Energy states diagrams

In this thesis, we examine a different approach to what students are doing in the physics classroom. They encounter many different representations of physics ideas: graphs, equations, tables, pictures, diagrams, and words. These representations of physics ideas are each by themselves incomplete. It takes an act of assimilating, coordinating, and moving easily between many different representations in order to create understanding. Therefore the first ability students have to develop is the ability to represent ideas and physical processes in different ways and move between representations. Some representations may be familiar. Physicists are conscious of the role of equations and graphs in their reasoning. Physics education researchers have extensively studied students' difficulties with these representations and how to help students' master activities such as reading and interpreting graphs, or connecting equations to physical reality (Brookes, 2006). For this purpose we plan Multiple Representation Activities (MRA) to develop students' conceptual learning in Newton's Laws.

Chapter 2
Multiple Representation Activities (MRA)

Shulman (1986) identified representations as being part of teachers' pedagogical knowledge. He defined these representations as "including analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others". Specifically in mathematics, Ball (2008) also highlighted representations as being part of the 'specialized content knowledge' of mathematics unique to teaching. This specialized knowledge included selecting representations for particular purposes, recognizing what is involved in using a particular representation and linking representations to underlying ideas and other representations. A common justification for using more than one representation is that this is more likely to capture a learner's interest and, in so doing, play an important role in promoting conditions for effective learning. Teachers need to be able to draw on a variety of representations as there is "no single most powerful forms of representation" (Shulman, 1986).

Scientists are very skilled at flexibly and fluidly moving across multiple representations based on underlying principles. They use the features of various representations, individually and together, to think about the goals and strategies of their investigations and to negotiate a shared understanding of underlying entities and processes. Novices are less skilled in the use of representations and rely on their surface features for meaning. The students we studied had difficulty making connections between representations and the phenomena they stand for and making connections across the features of multiple representations to understand scientific phenomena in terms of underlying entities and principles (Kozma, 2003).

2.1. Understanding how to select an appropriate representation

In many multi-representational environments, not all representations are available at the same time. In this case, learners have to select the most appropriate representations for their needs. If this is the case, they may have to consider what goal they are seeking to achieve, what representations are available and what are their individual preferences (Ainsworth, 1999). For example, when solving Force and Motion problems, learners may need to focus on the task they are solving. If their current task is to find out the position from which an object started and they are currently working with a velocity-time graph, they should learn to select the distance-time graph. However, if they need to determine acceleration, they should learn that the distance-time graph is not ideal. They may also need to identify the nature of their personal preferences, for example, do they prefer to learn from tables or graphs? If so, would it be a good idea at this time for them to stay with their preferred form of representation or would it be good to try to focus on their least preferred representation to learn its value?

2.2. Understanding how to construct an appropriate representation

Learners may also be required to construct the representations themselves. They may be given specific instructions of the representation to construct such as “draw a velocity-time graph of a body which starts with an initial velocity of 0ms and then continues to accelerate at the rate of 9.8 m/s for 30 seconds. Find the average velocity”

Alternatively, they may be presented with a problem such as “a body starts with an initial velocity of 0 m/s and then continues to accelerate at the rate of 9.8 m/s, for 30 seconds, find the average velocity” which does not tell them which representations would be helpful. A further possibility would be to give learners the velocity-time graph of this situation and then ask them to construct other representations such as an acceleration-time graph or a table of velocity against time. In the first case, learners must know how to construct the appropriate representation, in the second case, they must know how to select an appropriate representation to construct before interpreting it correctly and in the third case, they must know how to interpret the first representation and the construct a second representation on this basis.

There is a lot of evidence that knowing how to interpret a representation does not mean that you know how to construct a representation correctly. Furthermore, knowing how to construct a representation does not guarantee that you can then use it to solve the problem you constructed it to solve. There are many educational benefits from encouraging learners to construct their own representations, not least that we want learners to be able to do so – imagine a world where people could read but not write. In addition, it may be the case that constructing your own representations leads to better understanding than interpreting a given representation (Van Meter and Garner, 2005). Grossen and Carnine (1990) found that children learned to solve logic problems more effectively if they drew their responses to problems rather than selected a pre-drawn diagram. Another innovative use of construction was explored by Schwartz and Martin, (2004) who allowed students to invent representations to help those understanding descriptive statistics and compared them to students who had been given solution and allowed to practice them. No student in the invented condition developed the correct solution. However, when comparing which group of students could then learn from a standard lecture and apply the solution to novel problems, the group who had invented solutions was better than the group who had practiced with the correct solution. Consequently, we need to consider allowing students construct their own representations, even if these representations are not ultimately the ones they will go on to use.

2.3. Understanding how to relate representations

If learners are working with an individual visualization, then they still need to master the cognitive tasks. However, there is one process that is unique to learning with more than one representation that of relating different representations. Unfortunately, there is good evidence that this can be extremely difficult for learners, yet it is a fundamental characteristic of expertise (Kozma and Chin and Russell and Marx, 2000). For example, Tabachneck and Leonardo and Simon (1994) report that learners of economics did not attempt to integrate information between line graphs and written information when both interpreting and constructing graphs. Combining inappropriate representations can even completely inhibit learning. Ainsworth and Bibby and Wood (2002) contrasted children learning estimation with two representations, either mathematical, pictorial or a mixed system of one pictorial and mathematical representation. By themselves, picture and mathematical representations helped children learn but those children who studied with the combination knew no more at the end of the study than they had at the beginning. It is also difficult to know how to support this process. For example, whether it is beneficial to teach learners to relate representations may depend upon a learner's prior knowledge. Seufert (1999) found that only learners with an intermediate amount of prior knowledge benefited from help with translation between representations. High prior knowledge learners did not benefit as presumably they could make these links for themselves. Low prior knowledge students also did not benefit because they became overwhelmed by too much new information. There are many roles that different combinations of representations can play in supporting learning.

Despite conflicting findings about the impact of multiple representations on learning outcomes, one result found consistently across studies is that learners find translating between representations difficult. Translation is used to refer to all cases when a learner must see the relation between two representations. It is used to refer both to the cases when a learner must comprehend the relation between two representations and also when they must act to reproduce this relation. It is neutral about whether translation occurs through direct mapping between the symbols or whether it is mediated through domain understanding. However, more detailed and critical analyses of performance revealed that the learner had failed to grasp important connections between the two modes of representation. Even after extensive experience with multi-representational learning experiences designed to teach understanding of functions, only 12% of students gave answers that involved both the numerical and visual representations. Most answers reflected the use of one representation and a neglect of the other. Such research suggests that appreciating the links across multiple representations is not automatic. An investigation by Ainsworth, Wood and Bibby (1996) demonstrates how the achievement of translation between one representation and another varies depending upon the nature of the relations between representations selected. To overcome problems in learning how to translate between representations, many learning environments have been designed to exploit automatic translation or ``dyna-linking". Here a learner acts on one representation and is shown the effects of their actions on another. It is hoped that is a system automatically performs the translation between representations, then the cognitive load placed on learners should be decreased and so free them to learn the relation between representations. Against this position, advocates of a constructivist approach to education might argue that dynamic linking leaves a learner too passive in the process. Such dyna-linking may discourage reflection on the nature of the translations leading to a concomitant failure by the learner to construct the required understanding. At present, such global issues cannot be resolved, and this is likely to remain the case until we understand more about the conditions under which multi-representational learning environments should be designed to support cross-representation translation. A conceptual analysis of existing multi-representational learning environments suggests there are three main functions that multiple representations serve in learning situations to complement, constrain and construct. The first function is to use representations that contain complementary information or support complementary cognitive processes. In the second, one representation is used to constrain possible (mis)interpretations in the use of another. Finally, multiple representations can be used to encourage learners to construct a deeper understanding of a situation. Each of the three main functions of multiple representations can be further sub-divided into several subclasses (Fig. 2.1).

Often a single multi-representational environment may serve several of the functions shown, but, to begin with, each class will be considered separately.

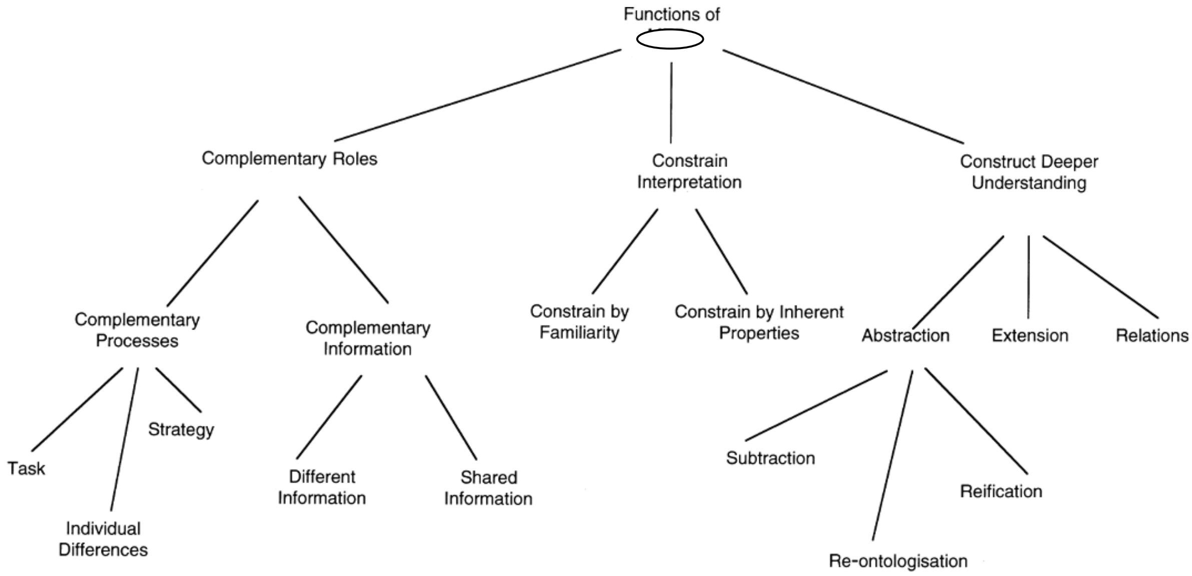


Figure 2.1.A functional taxonomy of multiple representations.

Using multiple representations in complementary roles: one reason to exploit multiple representationals in learning environments is to take advantage of representations that have complementary roles, where differences between representations may either be in the information that each contributes, or in the processes that each supports. By combining representations that complement each other in these ways, it is envisaged that learners will benefit from the sum of their advantages.

Multiple representations to support complementary processes: The most familiar rationale for using more than one representation is to benefit from the varying computational processes supported by different representations. There is an extensive literature showing that representations that contain the equivalent information can still support different inferences. One common distinction drawn is that between diagrams and sentential representations. For example, Larkin and Simon (1987) proposed that diagrams exploit perceptual processes by grouping together relevant information and hence make processes such as search and recognition easier. Further research has shown that other common representations differ in their inferential power. Three main classes of reasons for exploiting multiple representations with different computational properties are found (a) when different learners exhibit preferences for different ones, (b) when the learner has multiple tasks to perform and (c) when using more than one strategy improves performance. If a learning environment presents a choice of multiple representations, learners can work with their preferred choice. Where learners have varying degrees of experience and expertise with different representations, an appropriate combination leaves each free to select and exploit that with which they feel most familiar. More contentiously, it is often claimed that representational preferences stem not just from experience but are also influenced by more stable individual differences. Factors such as IQ, spatial reasoning, locus of control, field dependence, verbal ability, vocabulary, gender and age have been cited as candidates. A common is that lower achieving learners are more likely than their higher achieving peers to benefit from graphical representations of a task. Various taxonomies of cognitive style have been advanced, but this remains a controversial issue with findings of marked intra-individual differences as well as the proposed inter-individual ones. Thus, there is not necessarily a simple or face-valid relation between supposed cognitive style, representational preference and task performance. To function effectively in a domain, a learner is typically required to perform a number of different tasks. There is rarely, if ever, a single representation that is effective for all tasks; rather particular representations facilitate performance on some but not on others. There were significant interactions between task and representation, and no single representation proved better overall. Thus, participants given tables and diagrams identified faulty components faster than ones provided with information expressed as specific verbal rules. These participants, however, proved faster given the task of deciding which switches were mispositioned. Even in such a simple domain, we can see that multiple representations can be beneficial by providing representations that fit a task more effectively. Representations and problem solving strategies also interact. No single strategy proved more effective than any other. However, where the learner employed more than one strategy, their performance was significantly more effective than that of problem solvers who used only a single strategy. As each strategy had its inherent limitations, switching between them made problem solving more successful. Students were observed solving analytical reasoning problems they used a variety of representations (e.g. logic, set diagrams, tables, and natural language) although the majority of individuals stayed with just one in solving a problem. In only 17% of cases did participants use more than one representation, and this tended to be associated with better performance. Consequently, where learners are given the opportunity to use multiple representations, they may be able to compensate for any weaknesses associated with one particular strategy and representation by switching to another. It can be seen that there may be considerable advantages for learning with complementary processes because, by exploiting combinations of representations, learners are less likely to be limited by the strengths and weaknesses of any single one.

Multiple representations to support complementary information: A second reason to use complementary multiple representations is to exploit differences in the information that is expressed by each. Multiple representations tend to be used for this purpose either in cases where a single representation would be insufficient to carry all the information about the domain, or in cases where attempting to combine all relevant information into one representation would over-complicate the learner's task. In each case, there are two sub-classes of this category (a) where each representation encodes unique aspects of a domain and presents different information and (b) where there is a degree of redundant information shared by the two as well as information unique to each.

Using multiple representations that express different information: Where there is an excess of complex information to convey using multiple representations allows designers to create representations that are individually simpler and more usable. Yet, had it done so, the representation would have quickly become cluttered and difficult to interpret when more than a few worlds were displayed.

Oliver (1998) analysed the performance of learners working with the two representations and suggests that dividing the information across the two allowed learners to concentrate on different aspects of the task, making the learning goals more achievable.

Using multiple representations to support new inferences by providing partially redundant representations.Rather than provide representations that have completely different information, an alternative is to use multiple representations that provide some shared information, where partial redundancy of information supports new interpretations of the represented domain. These uses of representations is common when one representation is designed to provide functional information (e.g. a functional diagram of a heating system) and the other physical information (e.g. a map of the true positions of radiators, boilers, etc.). It is possible that a single representation could provide all the necessary information to support the required inference, but at the cost of raising additional problems of interpretation and transparency. By distributing information over such partially redundant representations, multi-representational learning environments can create less complicated artifacts, but then introduces demands for translation and integration of a dilemma that is considered later.

Using multiple representations to constrain interpretation: A second use of multiple representations is to help learners develop a better understanding of a domain by using one representation to constrain their interpretation of a second representation. This can be achieved in two ways: by employing a familiar representation to support the interpretation of a less familiar or more abstract one, or by exploiting inherent properties of one representation to constrain interpretation of a second.

Using multiple representations so that a familiar representation constrains interpretation of a second unfamiliar representation: One rationale for exploiting a familiar representation is to support the interpretation of a less familiar or more abstract one and to provide support for a learner as they extend, or revise misconceptions in, their understanding of the unfamiliar. Here, the primary purpose of the constraining representation is not to provide new information but to support a learner's reasoning about the less familiar one. It is the learner's familiarity with the constraining representation, or its ease of interpretation, that is essential to its function.

Using multiple representations so that the inherent properties of a representation constrain interpretation of a second representation: In contrast to these cases, there are situations where an abstract or unfamiliar representation can be exploited to constrain the interpretation of a second representation by exploiting some inherent property. For example, graphical representations are generally more specific than sentential representations. If someone is provided with a representation in a natural language expression such as `the knife is beside the fork', there is inherent ambiguity about which side of the knife the fork has been placed. This is not possible when representing the same world pictorially, since the fork must be shown as either to the left or to the right of the knife .So, when these two representations are presented together, interpretation of the first (ambiguous) representation may be constrained by the second (specific) representation independently of issues of familiarity or experience. In other words, one representation can act to force an interpretation of another one.

Using multiple representations to construct deeper understanding: It has been claimed that exposure to multiple representations leads to deeper understanding.

Using multiple representations to support abstraction: Abstraction is a notoriously slippery term. One use of the term is equivalent to `subtraction', where the emphasis is on detecting and extracting only a sub set of features from the initial representation. An alternative conceptualisation emphasises re-ontologisation rather than simply subtraction. So how might multiple representations encourage abstraction? It is hoped that by providing learners with a rich source of domain representations they will translate or construct references across these representations. Such knowledge can then be used to expose the underlying structure of the domain represented. Learners can discover invariant properties of a domain in the face of perceptually salient but conceptually irrelevant differences in the appearance of any specific instance: a form of analysis by synthesis.

Using multiple representations to support extension: Extension or generalisation can be considered as a way of extending knowledge that a learner already has to new situations, but without fundamentally changing the nature of that knowledge. In contrast to abstraction, extended knowledge does not require re-organisation at a higher level. When considering representations, extension can refer to two different aspects of a learning situation of extending the domains where a given representation is used or extending the way that domain knowledge is embodied to include other representations. The first case of extension can be seen whenever a representation, taught for one purpose or in one domain, is used to serve another. For example, common representations such as tables and graphs might first be taught in the maths classroom. Subsequently, they can be used for representing information necessary to solve problems in physics, geography, economics, etc. However, this type of extension, although common in learning situations, is outside the scope of the present analysis as it concerns the application of a common representation to multiple fields, rather than the use of multiple representations to support learning in a common domain.

The second type of extension is extending domain knowledge through its expression in a variety of representations. For example, learners may know how to interpret a velocity time graph in order to determine whether a body is accelerating. They can subsequently extend their knowledge acceleration to such representations as tables, acceleration-time graphs, tickertape etc. This process counts as representational extension if a learner exploits an understanding of how one representation expresses a concept to gain some understanding of the way in which a second representation embodies the same knowledge.

Using multiple representations to teach relations among representations: This function of multiple representations is only subtly different from the cases that have already been considered. Similar to extension, the pedagogical goal is explicitly to teach learners how to translate between representations. However, in this case teaching does not extend from knowledge of one well-understood representation to a second. Instead, two or more representations are introduced simultaneously and learning to translate between them is more of a bi-directional process.

The role of translation in learning with multiple representations: There are many different reasons why multiple representations can be beneficial for learning. It was suggested that multiple representations are commonly used for one of three main purposes (i.e. that multiple representations can provide complementary information and processes, can constrain interpretations and help learners construct a deeper understanding of the domain). For each of these uses, multiple subcomponents were identified. Furthermore, multiple representations used in a single system may fulfill two or more of these purpose either simultaneously or sequentially. Identifying the different functions that multiple representations play is crucial as each makes distinct predictions about how the learning goals should be supported. In each case, it is the role of translation between representations which influences the fit between the design and the learning objective(s). The first use of multiple representations is to support complementary processes and information. This design is ideal if one representation would be very complex to interpret when it included all of the necessary information. It is also advantageous when the computational properties of alternative representations support and focus on different aspects of the domain or encourage different strategies. As each representation contributes something separate to the process of learning, one way to make the learning task more tractable is to discourage users of a system from learning to translate between representations. This argument is based on the abundant evidence that translating between representations can be very difficult. Furthermore, if translation is not necessary to achieve the particular function of the learning environments representations, then providing co-present representations may encourage learners to attempt to relate them, so inhibiting the achievement of learning outcomes. Therefore, to maximize this use of multiple representations, the learning environment should automatically perform translation between the representations, thus freeing the learner from trying to perform this task. Alternatively, it may be appropriate to present the representations sequentially to discourage attempts at coordination. The second category of use of multiple representations is to constrain interpretation. For example, this can be seen when a known representation supports the interpretation of an unfamiliar abstract representation The third category of multiple representations is when learners are encouraged to construct a deeper understanding of a domain. It was suggested that this could occur through abstraction, extension or by directly teaching the relation between representations. This goal provides designers with hard choices. If users fail to translate across representations, then deeper understanding may not occur. Yet, representations which provide the different viewpoints normally needed for deeper understanding are those that previously have been shown to be the most complex to relate. Furthermore, educational practice that emphasizes the role of the learner in actively constructing their own understanding would suggest that dynamic linking leaves a learner too passive in this process. This over-automation may not encourage users to reflect actively upon the nature of the connection and could in turn lead learners to fail to construct the required deep understanding. The question that remains is what the best way is to achieve the cognitive linking of representations in the mind of the learner. One approach to this problem is by scaffolding and, in particular, contingency theory .This approach suggests that the level of support provided to the learner for any given task should vary depending upon their performance. As a learner succeeds, support should be faded out, but upon failure, then the learner should receive help immediately. In order for a learner to achieve the cognitive linking of representations, the strategy suggested by scaffolding is to alter the implementation of dynamic linking in response to learners' needs, fading this support as their knowledge and experience grows. Thus, when learners are new to the task, full linking could be provided between representations. As their experience grows, then full linking could be replaced by some signaling of the mapping between representations. Finally, if learners can make the representations reflect each other manually (acting as the dynamic linking did initially), then they should be able to work independently on either representation. None of the systems reported in this paper yet takes this approach to designing for deeper understanding, although many could be altered to adapt to this view.

So far, it has been argued that multiple representations are used to support many different functions and that these functions can be distinguished by the role that translation plays in delivering these functions. This leaves software developers and teachers with a further important question of how can they tell when a multi-representational learning environment is successful. As multiple representations are used for many different purposes, the learning objectives they are designed to support require different assessment. Again, given the varying roles of translation in the process, it is unsurprising that ways of assessing the successful learning differ in the need to identify whether learners can understand the relation between representations in addition to understanding each representation in isolation.

Complementary information and processes: When multi-representational learning environments are used for this purpose, it was argued that learners should not be required to understand the relation between the representations. Consequently, measures of performance taken to determine effectiveness of teaching do not require translation. For example, if each representation in the learning environment provides different information such that no redundancy of information exists between the representations in the system, then it is logically fairly simple to determine if each representation has been mastered. In this case, one would expect to see improvement in performance which required those dimensions of information that were presented in an understood representation and little or no improvement if a learner had not mastered the representation. When multiple representations are used to support different computational properties, then we need to assess competence on each representation in isolation. For example, we know that different strategies are associated with representations that have different computational properties. Examining the way that learners understand the syntax and semantics of each representation and the strategies it supports will allow us insight into the effectiveness of the multi-representational learning environment.

Constraining interpretation: When multiple representations are used to constrain interpretation, a second representation is often designed to support interpretation of an unfamiliar representation and does not itself provide new information. Learners are not expected to construct an understanding of the set of relations between representations; rather, they are required to exploit these relations to understand a more complex representation. This principle informs the type of learning outcome that designers and teachers should be exploring. Hence, assessment of the success of this use of multiple representations can again be measured by determining performance on representations in isolation. In this case, we need to identify whether their understanding of the constrained representation has improved as a result of using the learning environment.

Deeper understanding: If multiple representations are to be used to encourage deeper understanding by abstraction or extension, then learners must come to understand fully the relation between the representations. It is not sufficient to measure performance on representations in isolation; in addition we need to understand whether learners can translate between them. A number of techniques have been developed to explore whether learners can translate between representations. These include micro-genetic accounts and computational modeling. These methods while a useful tool for researcher are too time consuming to be applicable for formative evaluation or used by teachers in the classroom. One solution is to use learning environments that capture behavioral protocols.

Ainsworth, Bibby and Wood (1997) showed that some learners could master aspects of estimation accuracy by focusing on a single representation rather than translating information between them. This knowledge is crucial if you wish to encourage abstraction or extension or have distributed information between representations; in each of these cases, any selective focusing on one representation will defeat the learning objective. Measures such as representational co-ordination could be used by software developers to assess the design of learning environments during formative evaluation or by teachers (or intelligent tutoring systems) to monitor performance of individual children during learning sessions. They are appropriate when using multiple representations to encourage deeper understanding as they indicate the extent to which learners can see the relation between representations rather than focusing on how well they understand the domain. They can be used to predict learning outcomes and also could form the basis of dynamic models used to determine the degree of scaffolding learners need to understand the relation between representations.

Many of the activities used in this thesis draw on my experiences of teaching physics at the secondary, and college levels. Some of these activities have been designed using real-life situations that do not necessarily include technological or societal problems, and some of them use videos from Investigative Science Learning Environment (ISLE); they not only increase students' knowledge of facts and concepts but also, it has been found, improve problem solving skills and increase interest in science. In some of them students are asked to predict what they expect to happen before a demonstration and explain why they think it should happen' that way. Then they observe what happens and are asked to modify their previous explanation. In this bundle of activities the following are addressed:

Students are encouraged to actively engage in real life activities to promote scientific thinking and writing. Students create their own investigation based on ability and interest. Technology is infused throughout, with the use of videos, internet, and publishing programs to engage all learning styles. The use of visuals (video, photos, and diagrams) can also help students to understand the content. Graphic organizers, checklists, and other techniques are used to help students keep clear records and stay on task. Students are encouraged to verbalize their thinking with multiple opportunities for shared discussion and students are given ample opportunities to practice new skills.

2.4. Investigative Science Learning Environment (ISLE)

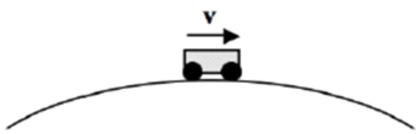
These processes involve observing, finding patterns, building and testing explanations of the patterns, and using multiple representations to reason about physical phenomena. ISLE is a comprehensive learning system that provides a general philosophy and specific activities that can be used in “lectures” (interactive meetings where students construct and test ideas), recitations (where students learn to represent them in multiple ways while solving problems) and labs (where students learn to design their own experiments to test hypotheses and solve practical problems). In ISLE, students are assessed for conceptual understanding, for problem-solving ability, and, most importantly, for their use of various scientific abilities (Rosengrant and Van Heuvelen and Etkina, 2009). They are activities that help students acquire some of the abilities used by scientists in their work: experiment design, model building, use of multiple-representations, evaluation, etc.

Another feature of ISLE is that students master the concepts that they devise by using various thinking and learning strategies and by being active participants in all parts of their learning. They learn to represent physical phenomena in multiple ways.

This process starts with the observational experiments: students learn to draw a picture of the apparatus, record data in a table, then draw a graph and look for patterns. Sometimes the instructor provides hints for a specific physical representation, for example, constructing free-body diagrams to help students see a pattern in the data. Students learn to convert one type of representation of a process to other types in order to help them identify patterns in phenomena and devise explanations. Then they use concrete representations to help construct accurate mathematical descriptions of processes. They use the mathematical descriptions to make predictions about the outcomes of testing experiments. After concepts have been constructed and tested, students use the different representations to reason qualitatively and quantitatively about physical processes a strategy commonly used by scientists. Students learn to take a more complex situation apart, solve the parts, and reassemble the parts to answer a bigger question.

For example an activity related to Newton's second law is shown below:

Representing and reasoning: A battery powered toy car moves at constant speed across the top of an almost frictionless circular hump, as shown at the right.



(a) Use the graphical velocity subtraction technique to decide if the car is accelerating when passing across the top of the hump and, if it is accelerating, to estimate the direction of the acceleration.
(b) Construct a free-body diagram for the car when passing across the top of the hump. Make the force arrows the correct relative lengths.
(c) Use Newton’s second law to qualitatively compare the results of parts (a) and (b) to be sure they are consistent. If not, revise your work on one part or the other.

Figure 2.2: Represent and reason: Analyzing the car's motion using different representations and looking for consistency among them.

To investigate this activity, firstly Newton's second law qualitative concept is building and representing to students, they learned that: (a) the net force that other objects exert on an object moving at constant speed in a circle points toward the center of the circle; and (b) the direction of the acceleration of this circling object also points toward the center of the circle (based on the use of the graphical velocity subtraction technique). Based on these observations, students realize that the familiar Newton's second law also applies to two-dimensional circular motion.

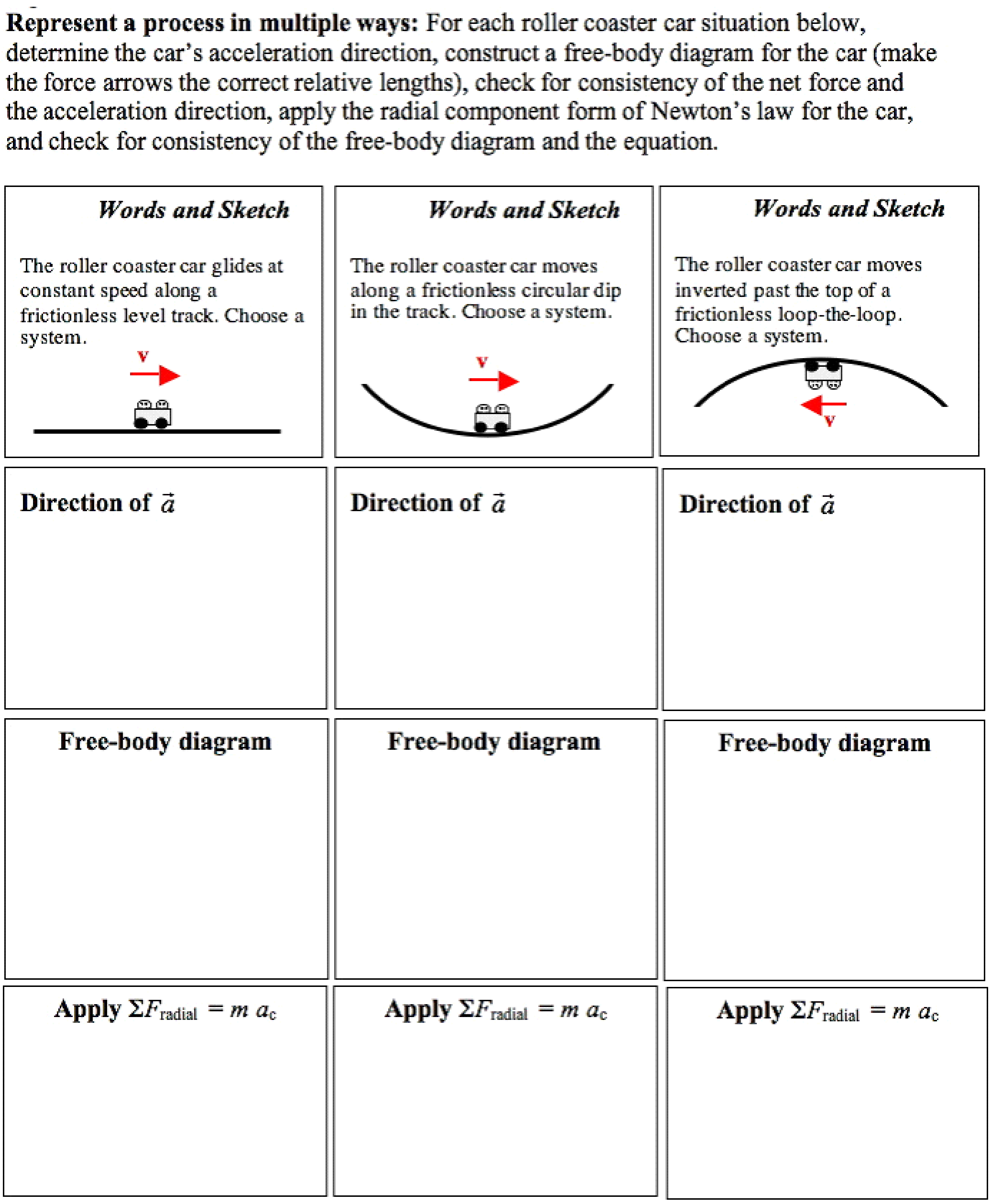
The next step is qualitative circular motion reasoning with Newton's second law: A very important aspect of ISLE is reasoning with multiple representations. An example of such a multiple representation reasoning activity is given in Figure 2.2 .When performing these activities, students do not look for a numerical answer. They work in groups of two during class and then the instructor discusses possible correct and incorrect answers. A follow up activity can be a multiple-choice question which students answer via a personal response system.

The third step is quantitative centripetal acceleration: We use the graphical velocity subtraction method to help students determine how the magnitude of the centripetal acceleration depends on the speed of an object moving in a circle and on the radius of the circle. Students, guided by the instructor, perform two activities that lead them to the understanding of how the acceleration is related to the speed of the object and the radius of the circle.

The next step is quantitative testing experiment for Newton's second law as applied to circular motion: Students now have Newton's second law in component form (from their study of translational dynamics) and a quantitative expression for centripetal acceleration. They can now use these concepts to make predictions about the outcomes of several testing experiments. One of them involves objects of different mass and the same surface placed on a rotating platform at the same distance from the center. Students need to use Newton's second law and their knowledge of circular motion to predict which object will fly away first. It is very important here that students actually draw free body diagrams and reason quantitatively before they make the prediction. As before, the prediction is counterintuitive all objects should fly off at the same time, and students often do not think that the experiment will work. However, the success of the experiment makes them feel confident about their ideas.

Representing processes in multiple ways is the next step. These activ ities ask students to represent a situation in different ways, including free-body diagrams, mathematics, etc. They do not solve problems to find a numerical answer. (Figure2.3)

The students are relating the abstract mathematical representation to more concrete sketches and diagrams. (Etkina and Van Heuvelen, 2003).



Represent a process in multiple ways: For each roller coaster car situation below, determine the car's acceleration direction, construct a free-body diagram for the car (make the force arrows the correct relative lengths), check for consistency of the net force and the acceleration direction, apply the radial component form of Newton's law for the car, and check for consistency of the free-body diagram and the equation.

Words and Sketch The roller coaster car glides at constant speed along a frictionless level track. Choose a system. v	***Words and Sketch*** The roller coaster car moves along a frictionless circular dip in the track. Choose a system. v	***Words and Sketch*** The roller coaster car moves inverted past the top of a frictionless loop-the-loop. Choose a system. v
Direction of $\vec{a}$	**Direction of** $\vec{a}$	**Direction of** $\vec{a}$
Free-body diagram	**Free-body diagram**	**Free-body diagram**
Apply $\Sigma F_{radial} = m\, a_c$	**Apply** $\Sigma F_{radial} = m\, a_c$	**Apply** $\Sigma F_{radial} = m\, a_c$

Figure 2.3: Represent a process in multiple ways: Moving from concrete to abstract representations to analyze motion and interactions.

2.5. Using Multiple Representation

Using MRA in conceptual learning of Newton's Laws has an important role, so we decided to choose some activities related to real life depending on Newton's Laws in ISLE. There is a role to select these activities, experiments or demonstrations related to real life for this study. We consider that papers, books, Internet sites, and workshops provide list numerous experiments for use in physics instruction. How can an instructor decide what experiments to use? How can she/he move away from traditional "cookbook" experiments in labs and from lecture demonstrations that have been reported to achieve little? This rule describes an approach to classroom experiments in which they serve roles closer to that in the practice of physics.

It is proposed that in the history of physics most of “classical” experiments fall into one of three groups: *observational experiments, testing theoretical model experiments,* and *application experiments*. Initial observational experiments occur when physicists study an unknown phenomenon, they help develop a new model. For example observations of the behavior of gases in the 17th century, observations of the spectra of gases in the 19th century. Before physicists conducted these experiments, they could not make theoretical predictions of what was going to happen.

Testing experiments are usually conducted to test or disprove a certain hypothesis, idea, or a prediction. For example Hertz's experiments tested Maxwell's predictions of electromagnetic waves. Physicists performing these experiments could use a theoretical model to make a prediction about what they expected to observe if their model was correct.

Application experiments utilize and synthesize physics concepts developed and tested earlier, for example planning a satellite exploration of a comet.

Experiments in traditional physics instruction are used as lecture and high school classroom demonstrations and as laboratory experiments. There are two pedagogical techniques used for lecture demonstrations. In a traditional course students observe an experiment and then the instructor explains what happened and why. In reformed instruction students predict what is going to happen before the experiment, and then reconcile their predictions with the observations that follow. The latter has proven to be more effective that the former. Students make predictions using their naïve conceptions and then modify these conceptions based on the outcome of the experiments. Traditional laboratory experiments usually have as a goal to verify a principle or a concept that the students already learned from the instructor. The emphasis is on quantitative analysis of data with a great deal of guidance on how to execute the experiment. The theory is often provided with the laboratory instructions.

In some non-traditional introductory physics courses such as Workshop Physics, experiments play a different role. Students make observations and invent a concept that explains them. This approach is much closer to the practice of real practice. It is suggested that this method can be taken father. It is proposed that all physics experiments used in instruction can be classified according to the goal of the experiment:

1) Observational experiment. The goal is to observe a new phenomenon. Students later devise explanations for the observations.

2) Testing experiment. The goal is to test whether the explanation devised for some observed phenomenon works. Students use explanations that they constructed to explain some type 1) experiment to predict an outcome of a new experiment.

3) Application experiment. The goal is to apply the explanation that has been tested in 2) to explain new phenomena or design technical devices.

Using different pedagogical treatments for these types of experiments, instructor can teach the students to differentiate between observational evidence and inferences. Students learn to test inferences experimentally and see the applicability of their ideas. They acquire science process skills.

Table 2.1 provides suggestions on how to implement this approach to the real time activitiesand experiments (Etkina and Van Heuvelen and Brookes and Mills, 2003). A reader can view observational and testing experiments described in the paper in real time and frame-by frame in videotaped experiments.

Table 2.1. Different types of experiments, their goals and pedagogical approaches.

Type of experiment	Pedagogical goal	When to use in instruction	Instructions for the instructor	Questions for the students	Where it can be used
Initial Observation Can be qualitative or quantitative	Let students observe a phenomenon to collect data, find patterns in them or devise an explanation	At the beginning of a unit, as a lead for the students to develop conceptual understanding	1. Choose a simple experiment with a clear pattern. 2. Do not provide explanations, elicit predictions or use scientific terms during the experiment. 3. Focus attention of the students on the necessary part. 4. Ask students what they saw. Insist that they use their records and do not make inferences. After they agree on the results of their observation, ask for possible explanations.	1. What did you observe? 2. What did you record? 3. What are possible explanations of your observations? 4. What physical quantities might help you understand the phenomenon? 5. Measure the quantities and record your observations in data tables. 6. Look for patterns by graphing the data. 7. Formulate a question from the pattern, and then propose a hypothesis to answer that question.	Lecture, lab
Testing of a Concept Can be qualitative Or quantitative	Let students test the explanations that they invented for an initial observationa	After students construct multiple explanations, they either design experiments to test them or predict the outcomes of the instructor chosen experiments based on their explanations	1. Have equipment ready so the students can see it while they are devising testing experiments. 2. Find new experiments whose outcome students can predict using the concept. 3. Have students discuss the outcomes of the experiment in relation to the concept.	1.What is the concept you want to test? 2. What equipment do you need? 3. What is your prediction? Is it based on the concept? 4. Why is there is a mismatch between your prediction and the outcome of the experiment? Do you need to revise the concept or testing experiment? 5. What did you ignore in your analysis that may have caused your prediction to be wrong?	Lecture, lab, Students can also design testing experiments as a part of their homework.
Application of a concept or multiple concepts . Can be qualitative or quantitative	Let students apply the concept that they invented and tested to explain other phenomena or to invent a device	After students Have confidence in the explanation or concept that is in agreement with a scientific explanation or concept	1.Choose experiments that are real-life based. 2. Have students articulate the concept that they use to explain them or predict the outcome. 3. Have students evaluate the precision of the device that they will build beforehand.	1.Define a problem. 2.Identify smaller parts of the problem (analysis). 3. Access relevant conceptual knowledge. 3. Identify variables to be used in the analysis and quantities to be measured. Identify and justify approximations. 5. Identify other solutions. 6. Choose criteria to use in deciding which is the best solution. 7. Evaluate solutions.	Lab if students need to build devices and lecture or lab for other tasks

This approach to experiments in physics instruction allows an instructor to move away from the treatment of experiments in which they “illustrate” or “verify” physics concepts to an approach that resembles practice in the real world of science. Implementing it, the instructor has to make a choice whether she wants the students to: (1) observe a phenomenon to identify patterns in the data and devise an explanation; (2) test the validity of their explanation; or (3) consciously apply an explanation or law.

We developed 10 activities with questions for the students that are consistent with this approach. Activities in this study contains a collection of 5 videotaped experiments (Appendix A) supplemented with questions that an instructor might use in a lecture or laboratory.

For example some of them as follow:

Activity 1- Demonstration: Doing in class

Try to pull a sheet of paper out from underneath a breaker of water without spilling any water. Pull out the tablecloth without spilling a drop. Try different volumes of water.

Figure 2.4. Activity 1.

For example activity 1 as an initial observational experiment is discussed;

Pull a sheet of paper out from underneath a breaker of water without spilling any water and let students observe the horizontal motion of the paper. Students observe that the paper, which has been pulled horizontally, is out of table but the glass is standing on the table without spilling a drop.

Testing experiments

Qualitative

The instructor then asks the students to design an experiment to test if the explanation above is correct. The instructor might also ask students to predict the outcome of a new experiment using the explanation above.

Quantitative

After testing the independence of pulling paper qualitatively, the same pull is repeated while the different volumes of water are in the glass. The experiment can be repeated with different initial vertical speeds. Students can test whether the relation between speed of pulling and volume of the water or other factors in this experiment. They then predict what speed of water and initial situations needs to predict the goal of this experiment. Then they could relate the results with Newton's Laws and forces.

Applications

Qualitative applications

1. Show above demonstration to the students, ask them to explain it using a concept that was tested before, and decide how they will test their explanation.

2. Ask the students to predict the results of a demonstration before they see it using a concept that they have tested before and then reconcile their prediction with the actual experiment.

3. Perform a demonstration. Ask students to predict what will happen if some parameter in the experiment is changed using the concepts that they have constructed before.

Quantitative Applications

1. Students design an experiment to answer a question. For example the same experiment can be done with a coin on the paper on the surface of a glass filled with water.

2. Students design a measuring instrument (or a method) and indicate the limits of its measuring ability.

3. Students make a prediction so that something occurs successfully on the first try.

Activity 3 is a videotaped activity, which contains of qualitative and quantitative approach of different types of experiments.

Activity 3- Demonstration: Watching in class

On Rollerblades: Qualitative Observational Experiment-Video 1

Aim:

To observe the motion of an object when it does not interact with other objects and when it does interact with other objects. (Friction between the floor and rollerblades is negligible.)

Description of the Experiment

Observe what is needed for Eugenia to start moving. Notice what happens when she interacts with other objects. Notice what happens when she does not interact with other objects.

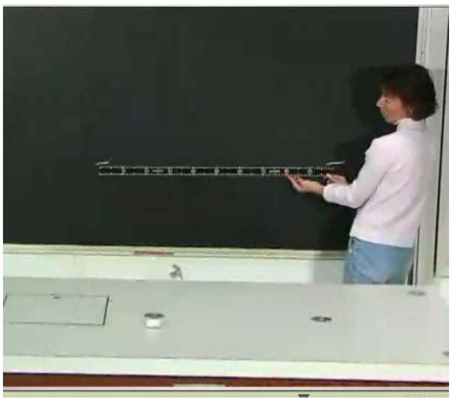

(a)


(b)

(c)

(d)

(e)



(f)

Figure 2.5. Activity 3.

Questions:

- What was necessary for Eugenia to start moving? Consider the different ways in which she got moving. What did they have in common?
- What was necessary for Eugenia to keep moving?
- What did Eugenia have to do to stop moving?
- What can you say about Eugenia's speed after David pushed her once? How do you know? With respect to what observer did you make your statement? What observers would see Eugenia speeding up or slowing down after David pushed her? What observers would see her moving with constant velocity?
- Represent Eugenia' motion during the moment when David pushes her, after he pushed her (several instances) and when she stops using motion diagrams and force (free-body) diagrams. Find a pattern in those diagrams. How are the two diagrams for each instance related? What assumptions did you make?

<u>Activity 9- Demonstration: Video 4-Watching in class</u>

Ball constrained to a ring: Qualitative Testing Experiment

Aim:

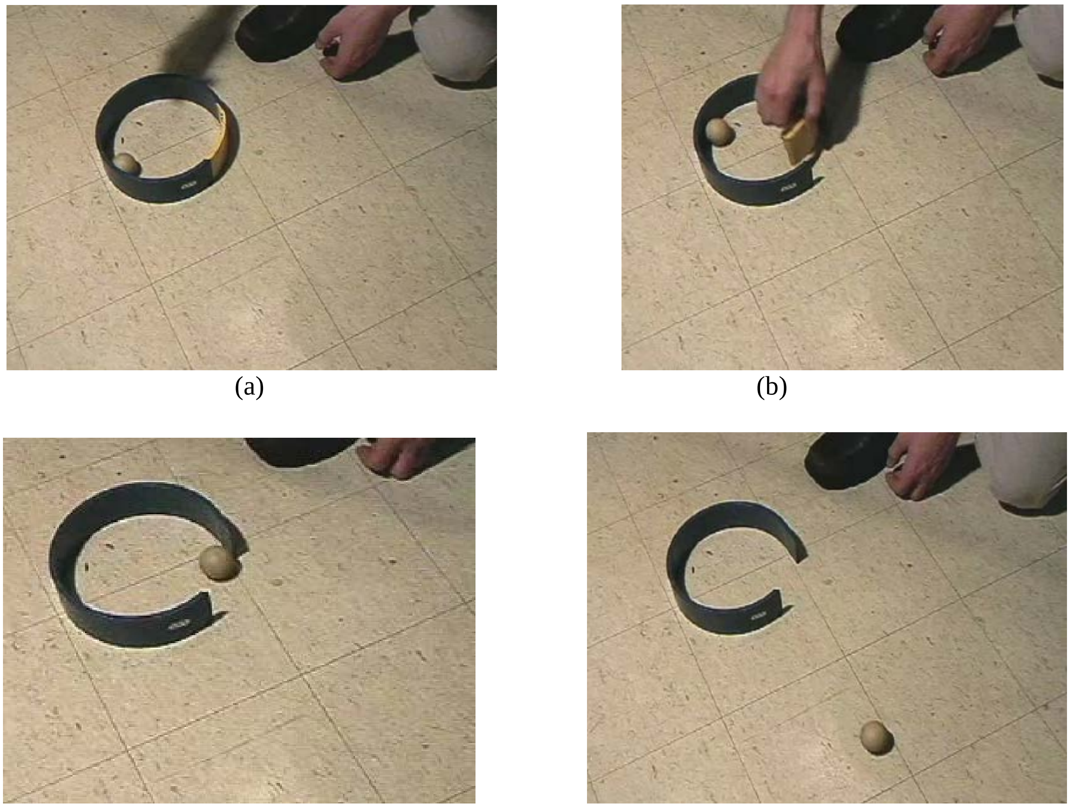
To test the necessary conditions for circular motion at constant speed.

Description of the Experiment

A wooden ball is placed inside a large metal ring placed on a flat surface, and set in motion inside of the ring. Part of the ring can be removed, making a gap and allowing the ball to escape from the ring.

Use your understanding of circular motion to predict what the path of the ball will be after it reaches the gap.

- Explain your prediction; make sure it is based on what you learned from the previous experiments.
- What other models do you need to use/assume to predict the path of the ball after it exits the ring?



(a) (b) (c) (d)

Figure 2.6. Activity 9.

Questions:

Now that you have watched the video, did your prediction agree with what you observed? If your prediction did not match the outcome of the experiment, decide how you need to change your reasoning that led to the prediction to explain what you see.

Chapter 3
Methodology

This chapter outlines the research design, background and participants, teaching strategy, instruments used for collecting data, data analysis, plan and timeline of the study.

3.1. Research Design

The purpose of this study is to investigate the effect of active learning method (consisting: Multiple Representation Activities and Interactive Conceptual Instruction) on level of students' understanding in Newton's Laws and analyzing mechanics situations.

Being exposed to phenomena and open questions and being encouraged to think as a physicist was more important than providing the theoretical background along the traditional lines of the sub disciplines and theories of physics (Mudde, 2008).

To help students recognize their abilities to understand the environment, it needs to engage students in appropriate activities, and to find ways to assess students' performance by formative assessment activities. For example, educational researchers found that if the verbal explanation or reading is not accompanied by visual representations, students are often unable to remember most of the key ideas or to apply the concepts to similar situations (Carney and Levin, 2002).

Meaningful learning occurs when a learner selects relevant information, organizes it into coherent representations, makes connections among corresponding representations in each channel(Mayer, 1997), and builds mental representations from the words and pictures. A well-designed educational multimedia presentation incorporates the use of both auditory and visual channels in order to increase the memory input capacity and employs the multimedia design principles (Moreno and Roxana and Mayer, 1999). This work focuses on comparing two methods of teaching to achieve to a better understanding of environment through Newton's laws.

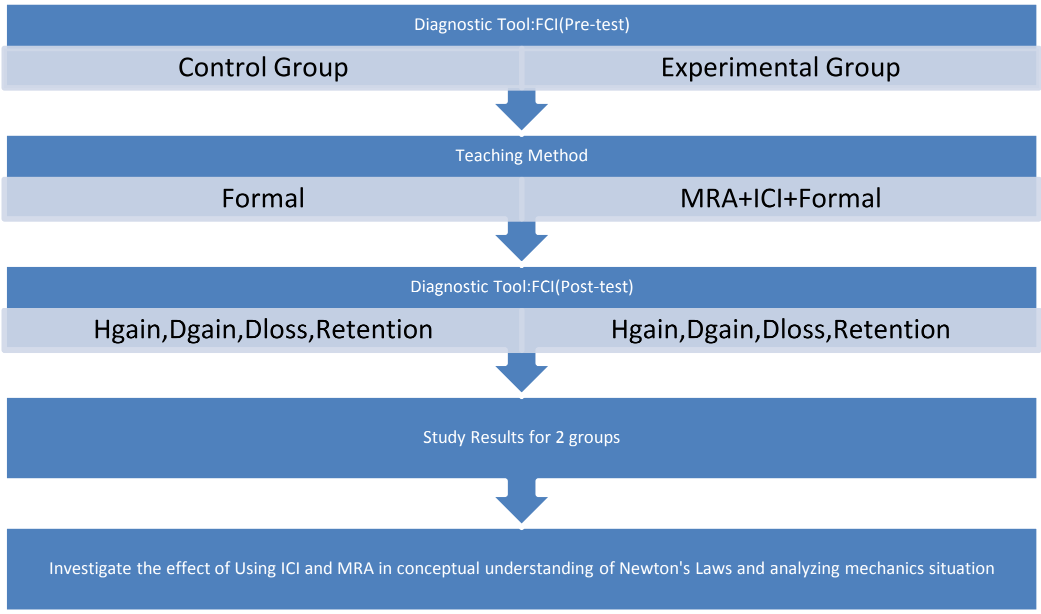


Figure 3.1. Research Design.

3.2. Research Timeline

The educational year for High schools in Iran is formally divided into two semesters, 17 weeks for each semester. The first semester is between before the October and after the January. The second semester is from before the February to the middle of June. This research collected data in the first semester in the educational year of 2012; between October 2012 and February 2013.

Table 3.1. The timeline of research(TM: Traditional Method).

Activity	**October 2012**				**November 2012**				**December 2012**				**January 2012**				**February 2013**				**…..**
	week																				
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	
TM																					
FCI(pretest)																					
MRA+ICI																					
FCI(posttest)																					
Final Exam																					
Doc. Analysis																					
Data Analysis																					

3.3. Background and Research Participants

There are currently non-governmental and governmental high schools in Iran. The schools are separated for girls and boys. Anecdotal evidence suggests that the general method of teaching introductory physics is often the traditional didactic pedagogy in which the lecturer behaves as an expert who transmits knowledge to the students. It is a teacher-centered approach in which the teacher plays the most significant role in the classroom, students are obedient; they study by listening to the teacher and taking notes quietly. Teachers typically explain the content according to the textbooks and give students notes to copy. The content is inflexible. There are very few students who take part in arguing or discussing ideas in the class, consequently students do not develop good understandings of physics concepts, and students' interest in physics is low and their development of understanding of physics concepts is limited.

This research is done in a governmental girl high school, which students are randomly in different level of talent and educational background. The age of students in high schools is between 15 to 18, and students study physics in all levels. Research participants are 16 years old (level-10). In this level students study Newton's Laws for the first time in formal curriculum. The subject of Newton's Laws in level-10 Physics text books has a mathematical approach, with the purpose of solving problems. The results of researches for level-10 high school students in Iran shows not only students have so many difficulties with solving problems in Newton's Laws , but also they do not have conceptual understanding of Newton's Laws. The majority of students are not able to interpret mechanics situation using Newton's Laws correctly. Researchers and physics educators recognize this problem and continuously try to improve their methods of teaching physics.

The sample consisted of 41 secondary girl students in Somayeh high school in the region 5 in western district of Tehran, Iran. The sample was randomly selected from second year student (level 10) undertaking an introductory mechanics course (linear and rotational kinematics and dynamics, work and energy) and the sample were randomly divided into a control group (Traditional, N = 20), experimental group (Interactive Conceptual Instruction, N = 21).

3.4. Teaching Strategy

In this study we focus on comparing two methods (traditional and active learning which we refer ICI) (Savinainen and Scott, 2002) of teaching to achieve to a better understanding of environment through Newton's laws. Forming a meaningful understanding of Newton's laws of motion is formidably difficult for beginners. A variety of teaching approaches have been developed to try to assist students to develop a meaningful understanding.

The course consists of two seventy-minute lecture sections per week for formal teaching and for applying ICI (Interactive Conceptual Instruction) in experimental group, 20 minutes per week is added as an extra class. Regular teacher for both of groups is the same. The extra class for experimental group starts with some demonstrations or videotaped experiments, and students are asked to identify objects interacting with the object of interest and then to make front view free-body diagrams. They are guided through the process of carrying out, making sense of, and modeling their experiments in multiple representation activities. The learning processes are collaborative and cooperative. Collaborative learning, in which students work in groups to solve problems, perform exercises, has positive effects on achievement, and cooperative learning relies upon social interactions among students (Gabel, 2003).

There is no unique answer to the question: What is the best way to teach a particular subject? Different students will respond positively to different approaches .If we want to adopt the view that we want to teach all our students (or at least as many as possible), then we must use a mix of approaches (Redish, 1994).

The teaching approach (which we refer to as Interactive Conceptual Instruction, ICI) was developed to promote conceptual understanding of the force concept and was based on the premise that developing an understanding of mechanics requires an interactive process in which there is opportunity for ideas to be talked through, and thought through, between teacher and students. In other words, the process should be consequent upon ongoing teaching and learning dialogues. Interactive Conceptual Instruction entails four features or components, which overlap with each other to some extent:

• Conceptual focus

• Classroom interactions

• Research-based materials

• Use of texts

The first feature involves focusing on the development of conceptual understanding. In ICI conceptual focus is achieved by utilizing the principle of 'concepts first' (Van Heuvelen, 1991), where new ideas are first developed at a conceptual level with little or no mathematics. This contrasts with traditional approaches where definitions are usually introduced, and expressed, in mathematical form. In ICI, the teaching often starts with demonstrations of phenomena, which act as a focus for observation and discussion, leading to an introduction by the teacher of the relevant physics concepts. Only after the students have a good grasp of the concepts is quantitative problem solving introduced.

The second feature of the ICI teaching approach involves promoting different forms of classroom interactions and is based on the premise that meaning making is a dialogic process where students benefit from talking through their developing ideas. In particular, Peer Instruction, as developed by Mazur at Harvard University, is used to actively engage the students in the learning process. The use of peer-instruction can increase the effectiveness of conceptually difficult courses well beyond that obtained with traditional methods (Hake, 2006).

The third feature of the ICI teaching approach involves use of research-based materials. Question-and-answer conceptual activities designed by the teacher are used in the early stages of meaning making. These activities enable constant feedback on developing student understanding. Research-based activities serve as diagnostic tools, which allow for more reliable formative assessment of student understanding as the teaching sequence progresses. Research-based activities can reveal difficulties that students may still have and inform further teaching on the topic. The fourth feature of ICI involves the ways in which texts are used to promote understanding. The students do not take ordinary notes; instead they make additions, remarks and underlining in the textbook. Here the focus is on interacting with, and coming to an understanding of, the text, rather than on copying out words from one page to another. In addition, the students are often asked to read the relevant section of the textbook prior to the lesson, thereby releasing time for active discussion. Concept maps, which are constructed by the teacher, are also used as a means for summarizing sections of work. The concept maps allow the students to see 'the big picture' and the relations of key ideas in a concise form. In addition, students are encouraged to write their own summaries of work completed. The ICI approach would offer the potential to promote enhanced learning gains in conceptual understanding of mechanics. In this study the extra class for ICI group, the students in groups (peer- instruction) are asked to answer the demonstration questions. The students' answers for MRA exercises were collected before the teacher gave the correct answers. Especially students will have certain difficulties, it is important that the tendency to make a particular error be deliberately exposed and then explicitly addressed. Once an error is elicited through an appropriate task, the student can be helped to recognize and confront the difficulty. At that point, it is crucial that the instructor insist that the difficulty be resolved. If this is not done, the difficulty is likely to remain latent and arise later in a different context (McDermott, 1997).

3.5. Research Instrument; FCI

The independent variables are two different methods of performing teaching which are divided into traditional and active learning. The Dependent Variable in this study is conceptual learning of Newton's Laws, the skill which we will explore the changes in these two domains separately for each groups before and after the study's treatments and compare them with each other. To evaluate the effect of the treatment on student learning (Dependent Variable), some baseline is needed.

The Force Concept Inventory (FCI) is an instrument used to assess students' beliefs about force and Newton's Laws. Students have many common-sense views about motion both before and after formal instruction. Questions on the FCI test were designed to be meaningful to students without formal training in mechanics and target their preconceptions on the subject (Hestenes and Well and Swackhammer, 1992).

It is part of a sequence that led to the development of the instrument (Halloun and Hestenes, 1985). Hestenes, Wells and Swackhamer (1992) designed FCI to probe student beliefs about force and how their beliefs compare with the many dimensions of the Newtonian concept. One of their outstanding virtues is that the questions probe for conceptual understanding of basic concepts of Newtonian mechanics in a way that is understandable to the novice who has never taken a physics course, while at the same time rigorous enough for the initiate. Most physicists would probably agree that a low score on the FCI test indicates a lack of understanding of the basic concepts of mechanics. However, there have been recent con and pro arguments as to whether a high FCI score indicates the attainment of a unified force concept. Nevertheless, even the detractors have conceded that "the FCI is one of the most reliable and useful physics tests currently available for introductory physics teachers" and that the FCI is "the best test currently available to evaluate the effectiveness of instruction in introductory physics courses."(Hake, 1997).

For this study we chose to use FCI to guide us to highlight the addressed misconceptions in questions. We did not focus on diagnosis of conceptions but by directly referring to questions in FCI to provide an instruction to handle misconceptions (Bulbul and Eryurt, 2011). Taking into consideration the positive effects of MRA, for the study we decided to plan representation activities of the FCI questions with ICI method and usage of the daily materials that we use.

The Force Inventory Concept is composed of 30 multiple choices items to probe student understandings of basic concepts in mechanics. Mazur has used the FCI at Harvard University to evaluate the successfulness of Peer Instruction (Crouch and Mazur 2001) and the FCI gains achieved have been amongst the best ever reported. It is usually given at the beginning and at the end of a course. Students tend to score higher on the test when it is taken the second time, following instruction.

FCI questions were articulated according to their appropriateness for real life presentation of Newton's Laws. Depending on the subject of each of these themes multiple representations activities was determined.

The FCI questionnaire is carefully translated into Persian language by one of physics teachers in Iran and reviewed by a group of experts. I gave the FCI as pretest on the second week of class. I took great care that all question sheets and answer sheets are returned. In order to promote serious effort on the pretest by students, I explained that although their scores on the pretest will not count towards the course grade, their scores will be confidentially returned to them and will assist both themselves and their instructors to know the degree and type of effort required for them to understand mechanics. I gave the FCI posttest unannounced near the final week of classes, and preferably as part of the final exam with significant course credit given for posttest performance. Giving course credit probably motivates students to take the posttest more seriously and thereby demonstrate more adequately their understanding, especially if time devoted to the posttest subtracts from time spent on the rest of the final exam (Hake, 2002). To review FCI test components, See Appendix B.

3.6. FCI Analyzing Method

The two analyses of pretest and posttest provide information on different aspects of course effectiveness. A cumulative analysis is used to determine instruction increases the likelihood of students acquiring and retaining baseline knowledge. A marginal analysis is used to determine whether course design is flexible enough to continually rebalance acquisition and retention efforts as student performance changes from one instructional method to the other.

The method used to quantify changes in performance is a definitive feature of any pre/post testing design. In next part I will state the definitions of Hgain, Dgain, Dloss, and Retention in analyzing results.

The following index is frequently used to measure the change in group performance from a pre-instruction to a post-instruction test.

$$g = \frac{\begin{Bmatrix} \text{average grade on the} \\ \text{post - instruction test} \end{Bmatrix} - \begin{Bmatrix} \text{average grade on the} \\ \text{pre - instruction test} \end{Bmatrix}}{100 - \begin{Bmatrix} \text{average grade on the} \\ \text{pre - instruction test} \end{Bmatrix}} \tag{3.1}$$

The ratio in (3.1), often referred to as normalized change (which in this study I refer Hgain, or Hake gain), expresses the difference between average test scores as a fraction of the maximum possible difference between these scores.

Hovland et al. (1949) used (3.1) to quantify the effectiveness of instructional films. Hake(1998) used (3.1) to gauge the relative effectiveness of various instructional techniques employed in introductory physics courses. Cummings et al. (1999) used (3.1) to evaluate innovations in studio physics. Meltzer (2002) used (3.1) to explore the relationship between mathematics preparation and concept learning in physics. These important studies relied on the intuitive notion that when comparing two courses:

"The course with the larger value of normalized change (g) is the more effective course."

Unfortunately, as Dellwo (2010) demonstrated, this classic assessment rule can lead to counterintuitive conclusions.

David R. Dellwo (2010) employed an alternate assessment rule obtained by decomposing normalized change (3.1) into component measures:

$$g = G - \gamma L \tag{3.2}$$

Here G is a normalized gain (which in this study I refer Dgain, or Dellwo gain) measuring the likelihood that a mistake on the group's pre instruction test is corrected on the post-instruction test. Similarly, L is a normalized loss (which in this study I refer Dloss, or Dellwo loss) measuring likelihood that a correct response on the group's pre-instruction test is rendered incorrect on the post-instruction test. The non-negative parameter γ is a renormalization factor dependent on the population's pre-instruction performance. Consequently, (3.2) expresses normalized change (3.1) as the difference between two non-negative indices, normalized gain and renormalized loss. The decomposition (3.2) gives rise to an alternative assessment rule that avoids the counterintuitive conclusions associated with last result, and reads in part:

"The course with the larger value of normalized gain (G) and smaller value of renormalized loss (γL) is the more effective course."

Normalized change (3.1) for a group of N students taking a diagnostic test with M questions can be expressed in the following form:

$$g = \frac{\theta_{post} - \theta_{pre}}{1 - \theta_{pre}} \tag{3.3.a}$$

$$\theta_{pre} = \frac{\begin{Bmatrix} Number\, of\;\; questions\; students\; answer \\ correctly\;\; on\; the\; pre\text{-}instruction\; test \end{Bmatrix}}{NM} \tag{3.3.b}$$

$$\theta_{post} = \frac{\begin{Bmatrix} Number\, of\;\; questions\; students\; answer \\ correctly\;\; on\; the\; post\text{-}instruction\; test \end{Bmatrix}}{NM} \tag{3.3.c}$$

The derivation of (3.2) is based on the following observation.

$$\begin{Bmatrix} \text{Number of questions} \\ \text{students answer correctly} \\ \text{on the post - instruction test} \end{Bmatrix} - \begin{Bmatrix} \text{Number of questions} \\ \text{students answer correctly} \\ \text{on the pre - instruction test} \end{Bmatrix}$$

$$= \begin{Bmatrix} \text{Number of questions students answer} \\ \text{correctly on the post - instruction test} \\ \text{and incorrectly on the pre - instruction test} \end{Bmatrix} - \begin{Bmatrix} \text{Number of questions students answer} \\ \text{incorrectly on the post - instruction test} \\ \text{and correctly on the pre - instruction test} \end{Bmatrix}$$

This observation together with definitions (3.3.b) and (3.3.c) imply

$$\theta_{post} - \theta_{pre} = G(1 - \theta_{pre}) - L\theta_{pre} \tag{3.4}$$

$$G = \frac{\begin{Bmatrix} \text{Number of questions students answer correctly on the post -} \\ \text{instruction test and incorrectly on the pre - instruction test} \end{Bmatrix}}{\begin{Bmatrix} \text{Number of questions students answer} \\ \text{incorrectly on the pre - instruction test} \end{Bmatrix}} \tag{3.5.a}$$

$$L = \frac{\begin{Bmatrix} \text{Number of questions students answer incorrectly on the post -} \\ \text{instruction test and correctly on the pre - instruction test} \end{Bmatrix}}{\begin{Bmatrix} \text{Number of questions students answer} \\ \text{correctly on the pre - instruction test} \end{Bmatrix}} \tag{3.5.b}$$

The numerator in (3.5.a) is the number of questions on which students demonstrate a gain in knowledge and the denominator is the maximum possible gain. Consequently, the ratio G is a normalized gain measuring the conditional probability (Ross, 2004) that a mistake on the group's pre-instruction test is corrected on the post-instruction test. Similarly, the numerator in (3.5.b) is the number of questions on which students demonstrate a loss in knowledge and the denominator is the maximum possible loss. Consequently, the ratio L is a normalized loss measuring the conditional probability that a correct response on the group's pre-instruction test is rendered incorrect on the post-instruction test.

In summary, equation (3.4) expresses change in test score as a difference between the fraction of questions on which students demonstrate a gain in knowledge and the fraction on which they demonstrate a loss of knowledge. Finally, to obtain (3.2) define

$$\gamma = \frac{\theta_{pre}}{1 - \theta_{pre}} \tag{3.5.c}$$

and divide (3.4) by $(1-\theta_{pre})$. The scaling factor (3.5.c) is a non-negative parameter whose value is larger than 1 if $\theta_{pre} > ½$, equal to 1 if $\theta_{pre} = ½$, and smaller than 1 if $\theta < ½$. The scale γ is referred to as the group's aspect ratio and specifies the odds that the group gives a correct answer on the pre-instruction test.

$$\text{i.}\quad \textit{A is more effective than B if:}\quad \begin{cases} G_A > G_B \text{ and } \gamma_A L_A \leq \gamma_B L_B \\ \quad\text{or} \\ G_A \geq G_B \text{ and } \gamma_A L_A < \gamma_B L_B \end{cases} \tag{3.6.a}$$

$$\text{ii.}\quad \textit{A and B are equally effective if:}\quad G_A = G_B \textit{ and } \gamma_A L_A = \gamma_B L_B \tag{3.6.b}$$

$$\text{iii.}\quad \textit{A and B are not comparable if:}\quad \begin{cases} G_A > G_B \text{ and } \gamma_A L_A > \gamma_B L_B \\ \quad\text{or} \\ G_A < G_B \text{ and } \gamma_A L_A < \gamma_B L_B \end{cases} \tag{3.6.c}$$

Notice, (3.6.a) restates "The course with the larger value of normalized gain (G) and smaller value of renormalized loss (γL) is the more effective course" in algebraic form and defines a consistent ordering of courses in the sense that if A is more effective than B and B is more effective than C, then A is more effective than C. Also, (3.6.c) offers an assessment option not offered by "The course with the larger value of normalized change (g) is the more effective course." , some courses are not comparable.

If A is a more effective course than B in the sense of (3.6.a), then $G_A - G_B$ is a value-added measure of improved effectiveness due to larger gains (Suskie, 2004). Also, γ is a value-added measure of improved effectiveness due to smaller renormalized losses experienced by students in the more effective course. Consequently,

$$g_A - g_B = (G_A - G_B) + (\gamma_B L_B - \gamma_A L_A) \tag{3.7}$$

is a value-added measure of the total improvement in effectiveness when (3.6.a) or equivalently "The course with the larger value of normalized gain (G) and smaller value of renormalized loss (γL) is the more effective course" applies and one course can claim the larger gains as well as the smaller renormalized losses.

On the other hand, (3.7) is not a measure of total improvement in effectiveness when (3.6.c) applies and neither course can claim both larger gains and smaller renormalized losses. In this case, one of $G_A - G_B$ and $\gamma_B L_B - \gamma_A L_A$ is positive while the other is negative; so (3.7) is the difference between two value-added measures:

$$g_A - g_B = (G_A - G_B) + (\gamma_B L_B - \gamma_A L_A) = \begin{cases} -(G_B - G_A) + (\gamma_B L_B - \gamma_A L_A) & \text{if} \quad (G_A - G_B) < 0 \\ (G_A - G_B) - (\gamma_A L_A - \gamma_B L_B) & \text{if} \quad (\gamma_B L_B - \gamma_A L_A) < 0 \end{cases} \tag{3.8}$$

That is, $g_A - g_B$ is a difference between added effectiveness due to larger gains in one course and added effectiveness due to smaller renormalized losses in the other course.

Finally, in view of (3.8), the classic assessment rule:" The course with the larger value of normalized change (g) is the more effective course" declares A more effective than B when either of the following applies.

• The added effectiveness due to smaller renormalized losses in A offsets the added effectiveness due to larger gains in B.

• The added effectiveness due to larger gains in A offsets the added effectiveness due to smaller renormalized losses in B.

Testing the effectiveness of research's idea by FCI and presenting the data on which it was constructed as Hgain(g), Dgain(G), Dloss and Retention is the goal of next chapter.

Chapter 4
Results

Testing the effectiveness of idea by FCI and presenting the data on which it was constructed as Hgain(g), Dgain(G), Dloss and Retention is the goal of this chapter. I will use the analysis to show how focusing on the Force Concept Inventory, a multiple-choice test is used to analyze students understanding in Newton's laws. I will present results for two groups of students that can be explained with the analyzing data.

4.1. Data Collection Procedures

For survey classification and analysis purposes I define:

(1) "Traditional" (T) course as that reported by instructor to make little or no use of ICI method, relying primarily on passive-student lectures and algorithm problem exams;

(2) "Interactive Conceptual Instruction" (ICI) course as that reported by instructor to make substantial use of ICI method;

(3) Average Hgain for both courses as the ratio of the actual average gain to the maximum possible average gain;

(4) Average Dgain measuring the likelihood that a mistake on the group's pre instruction test is corrected on the post-instruction test;

(5) Average Dloss, measuring likelihood that a correct response on the group's pre-instruction test is rendered incorrect on the post-instruction test;

(6) Average γ is a renormalization factor dependent on the population's pre-instruction performance and average value of renormalized loss (γDloss);

(7) Comparing averages for both groups to investigate effectiveness of method;

(8) FCI analyzing items for both groups.

4.2. FCI Analyzing for Traditional Group

The first set of data presented here (Figure 4.1) provide information about the distribution of pre and post-test scores for the traditional method teaching in control group. It is clear that the distributions of scores are very different for pre- and posttests. In the post test only 70% of the students (14 out of 20) exceeded the (20%) to the Newtonian world.

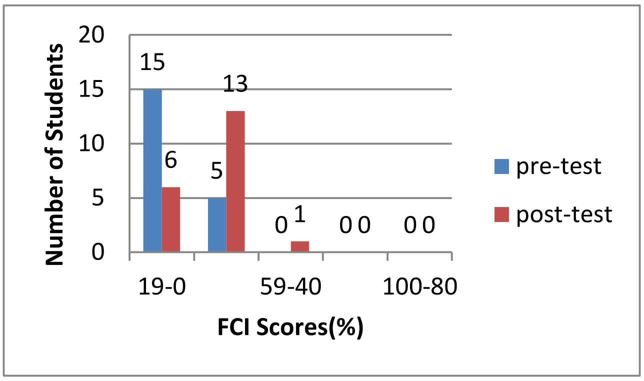


Figure 4.1. Pre- and post-test FCI score distribution for the control group (matched *n* = 20).

In Table 4.1.the pre and posttest results of individual students in control group are shown.

Table 4.1. Pre and posttsest results of students in control group.

	Last	First	Pre%	Post%
1	Abbasi	Zahra	17	20
2	Abbasipour	Maryam	17	23
3	Amoohasan	Sara	20	23
4	Anisheh	Samaaneh	17	23
5	Bamdadiyan	Mehrnoush	3	7
6	Chegini	Nastaran	23	30
7	Ebrahimi	Aarefeh	10	13
8	Ghoreishi	Zeinab	13	20
9	Golig	Fatemeh	10	17
10	Hesaaraki	Faaezah	13	27
11	Kazemi	Mobina	3	10
12	Majidi	Kimiya	13	17
13	Maleki	Farzaneh	17	20
14	Naseri	Fatemeh	10	20
15	Pakaavar	Aysan	20	23

16	Rahimi	Hanieh	20	20
17	Salehi	Farnoush	13	17
18	Same	Zeinab	13	20
19	Soleymani	Marjan	20	20
20	Tahoori	Farzaneh	17	40

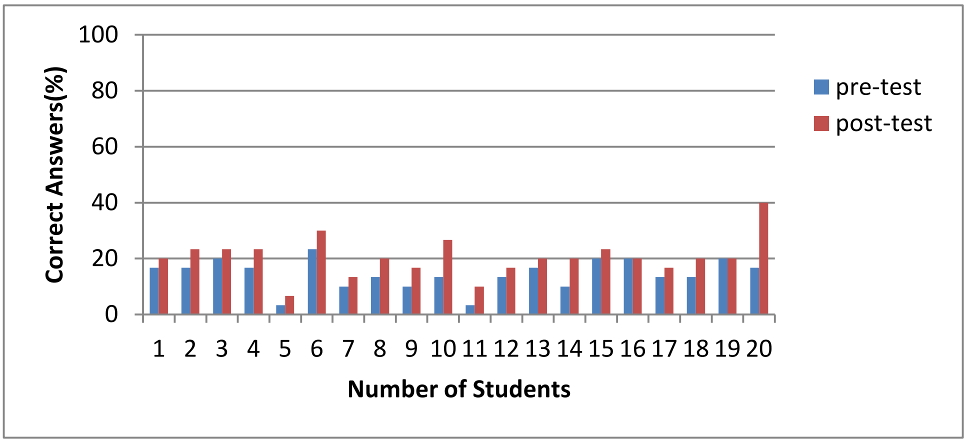


Figure 4.2. Pre- and post-test FCI correct answers (%) for individual students in the control group (matched *n* = 20).

The pre and posttest FCI correct answers (%) for individual students in the traditional group are presented in Figure 4.2.

The pre- and post-test scores for traditional group for individual items are presented in Figure 4.3 It is useful to calculate the average gains for individual test items (for example, using Hake's formula, the average gain calculated for item 4 is 0.66). These confirm quantitatively what can be observed from fig 4.1 Post-test scores are higher than pre-test scores in many questions (questions 1, 2, 3, 4, 5, 8, 9, 10, 15, 17, 18, 22, 26, 27, 29 and 30) but there are six questions (questions 6, 7, 11, 12, 13, 19, 23, 24 and 28) in which the post-test scores are actually lower than the pre-test scores. This implies that the teaching has had a negative effect in relation to students' responses to these questions.

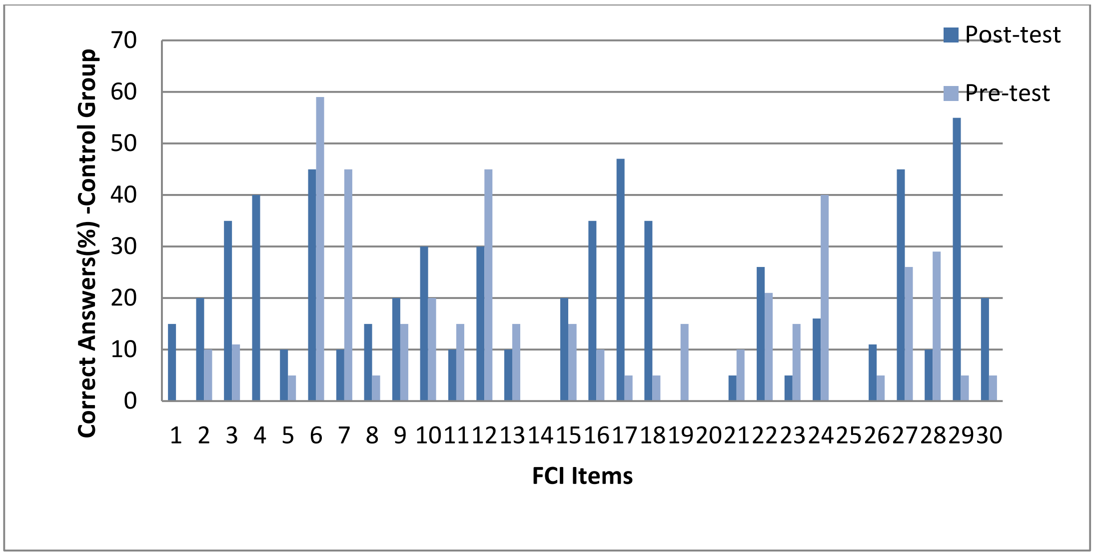


Figure 4.3. Correct Answers (%) of Control Group for FCI Items.

4.3. FCI Analyzing for ICI Group

The set of data presented here (Figure 4.4) provide information about the distribution of pre and post-test scores for the ICI method teaching in experimental group. It is clear that the distributions of scores are very different for pre- and post-tests. In the post-test, 95% of the students (20 out of 21) exceeded the (20%) to the Newtonian world and among them 0.28 of students (6 out of 21) exceeded the (40%) to the Newtonian world. The set of data presented in (fig 4.1) provide information about the distribution of pre and post-test scores for the traditional method teaching. In the posttest only 70% of the students (14 out of 20) exceeded the (20%) to the Newtonian world. Comparing data shows that improvement after instruction in ICI group is more than control group.

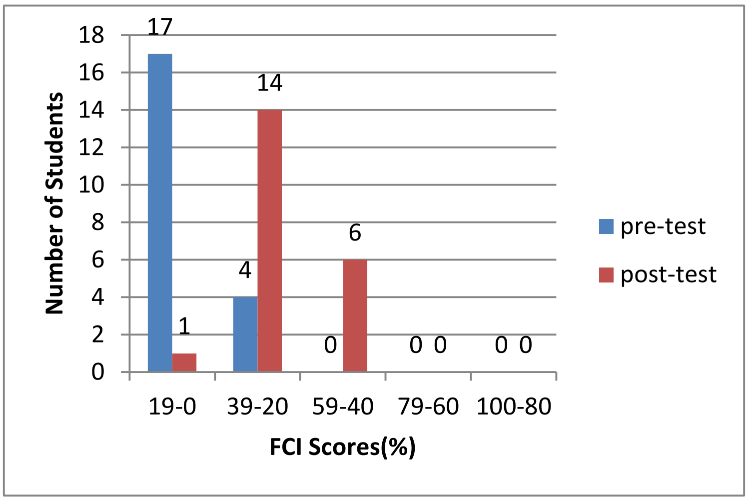


Figure 4.4. Pre- and post-test FCI score distribution for the Experimental group (matched n = 21)

In Table 4.2.the pre and posttest results of individual students in experimental group are shown.

Table 4.2. Pre and posttsest results of students in experimental group.

	Last	First	Pre%	Post%
1	Abdoli	Mahtab	3	27
2	Aghabalaaei	Sama	17	37
3	Ahmadi	Ghazaleh	10	20
4	Aliasgari	Fatemeh	7	20
5	Amiri	Sara	17	23
6	Banaei	Hanieh	10	37
7	Charati	Motahareh	7	33
8	Ebrahimi	Sana	20	20
9	Fallah	Zeinab	17	37
10	Hozhabri	Kimiya	20	47
11	Khani	Aatefeh	23	60
12	Metochi	Aida	7	43
13	Mohammadi	Maedeh	7	50
14	Moousavi	Sara	13	20
15	Moustofi	Delaram	17	37
16	Naderi	Shirin	3	37
17	Rabet	Fatemeh	30	43
18	Rostami	Nasrin	17	17
19	Rostami	Fatemeh	7	23
20	Tavakkoli	Zohreh	10	33
21	Tohidi	Fatemeh	3	53

The data presented in (Figure 4.2) provide information about the distribution of pre and post-test correct answers for the control group. Comparing Figure 4.5 Pre- and post-test FCI correct answers (%) for the experimental group, it is clear that the distributions of correct answers are very different for both groups, but in the post-test an improvement is seen for the experimental group(Figure 4.5.)

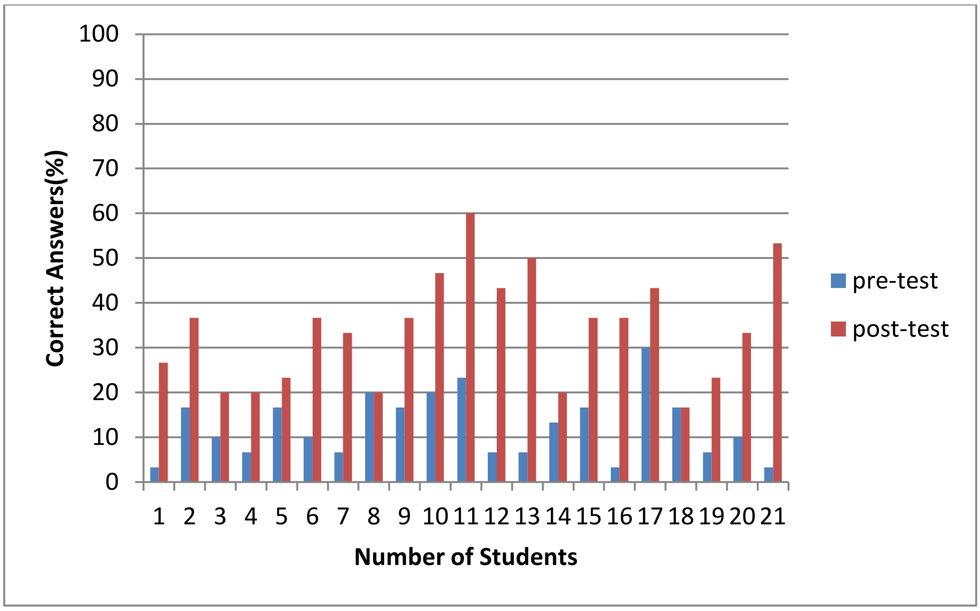


Figure 4.5. Pre- and post-test FCI correct answers (%) for the experimental group (matched *n* = 21).

The pre- and post-test scores for experimental group for individual items are presented in Figure 4.6. Posttest scores are higher than pre-test scores in many questions (questions 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 25, 26, 28, 29 and 30) but there are four questions (questions 9, 12, 24 and 27) in which the post-test scores are lower than the pre-test scores. This implies that the teaching has had a negative effect in relation to students' responses to these questions. Comparing results for control group in Figure 4.3 shows an improvement in scores for experimental group.

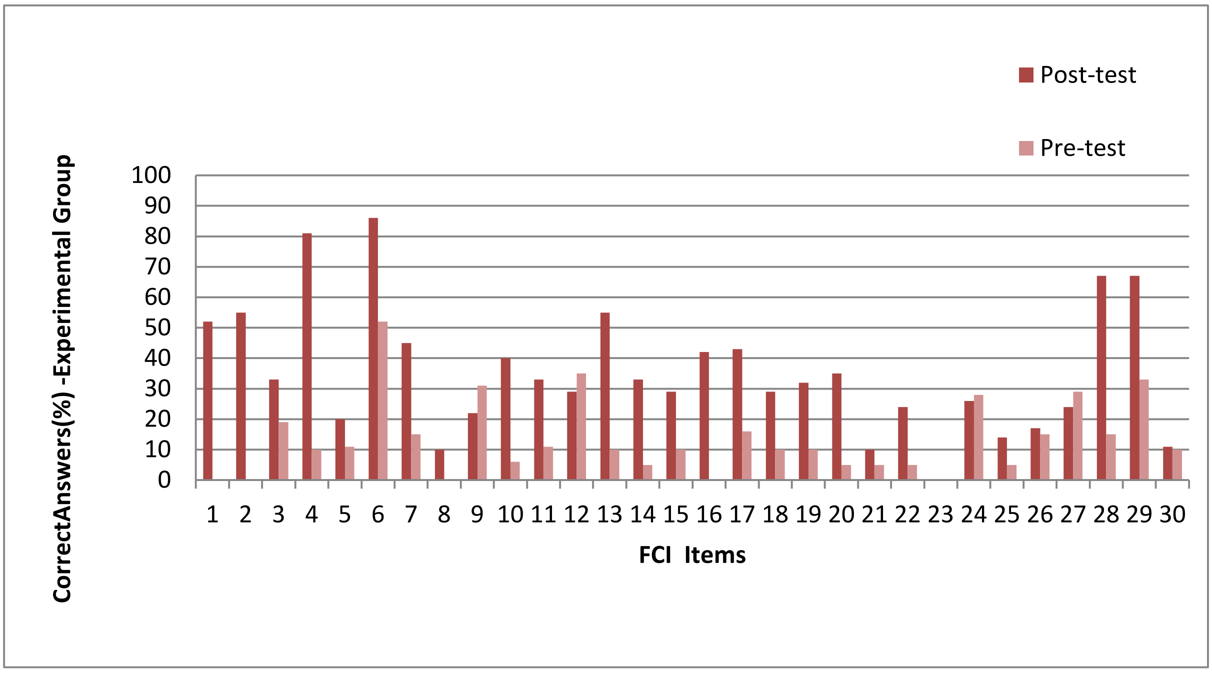


Figure 4.6. Correct Answers (%) of Experimental Group for FCI Items.

4.4. Hgain, Dgain, Dloss, Retention for groups

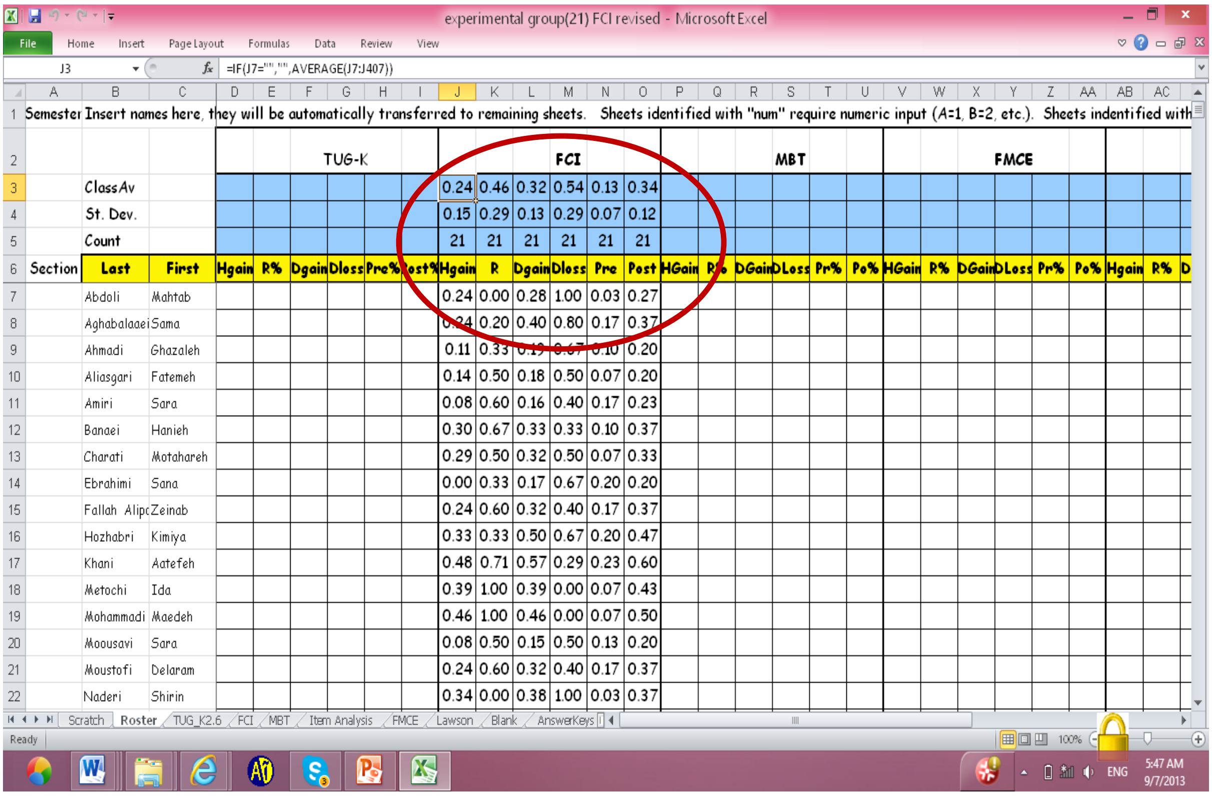
David Dellwo's paper on "Reassessing Hake's Gain" was presented at the Washington DC Winter 2010 AAPT meeting. In that paper Dellwo describes some sensible arguments on how to improve upon the Hake gain definition. Dellwo reasons a true "gain" would be one in which the student had pretested a problem incorrectly and posted the problem correctly. Likewise, a true "loss" would be a correctly pretested problem but incorrectly post tested problem. This allows for a true gain (Dellwo gain or "Dgain" - my definition, not his) and true loss (Dellwo loss or "Dloss"). Lastly, the student correct pre and posttest problems are defined as retention "R%". In analysis columns in Table 4.3.these new calculations for each student and in Table 4.4.for average of the class are included. Analysis for experimental group by Excel shows (Figure 4.7) pretest, posttest, Hgain, Dgain, Dloss, Retention (R) and standard deviation of them for each student and average of the class.

Table 4.3. FCI results for individual students in experimental group.

	FCI results for students							
	Last	**First**	**Hgain%**	**R%**	**Dgain%**	**Dloss%**	**Pre%**	**Post%**
1	Abdoli	Mahtab	24	0	28	100	3	27
2	Aghabalaaei	Sama	24	20	40	80	17	37
3	Ahmadi	Ghazaleh	11	33	19	67	10	20
4	Aliasgari	Fatemeh	14	50	18	50	7	20
5	Amiri	Sara	8	60	16	40	17	23
6	Banaei	Hanieh	30	67	33	33	10	37
7	Charati	Motahareh	29	50	32	50	7	33
8	Ebrahimi	Sana	0	33	17	67	20	20
9	Fallah	Zeinab	24	60	32	40	17	37
10	Hozhabri	Kimiya	33	33	50	67	20	47
11	Khani	Aatefeh	48	71	57	29	23	60
12	Metochi	Aida	39	100	39	0	7	43
13	Mohammadi	Maedeh	46	100	46	0	7	50
14	Moousavi	Sara	8	50	15	50	13	20
15	Moustofi	Delaram	24	60	32	40	17	37
16	Naderi	Shirin	34	0	38	100	3	37
17	Rabet	Fatemeh	19	67	33	33	30	43
18	Rostami	Nasrin	0	20	16	80	17	17
19	Rostami	Fatemeh	18	50	21	50	7	23
20	Tavakkoli	Zohreh	26	33	33	67	10	33
21	Tohidi	Fatemeh	52	0	55	100	3	53

Table 4.4. Class average Hgain, Dgain, Dloss, Retention, pretest, posttest for experimental group.

FCI results for class							
Experimental Group		**Hgain%**	**R%**	**Dgain%**	**Dloss%**	**Pre%**	**Post%**
	ClassAv	24	46	32	54	13	34
	St. Dev.	15	29	13	29	7	12
	Count	21	21	21	21	21	21



Section	Last	First	Hgain	R	Dgain	Dloss	Pre	Post
	ClassAv		0.24	0.46	0.32	0.54	0.13	0.34
	St. Dev.		0.15	0.29	0.13	0.29	0.07	0.12
	Count		21	21	21	21	21	21
	Abdoli	Mahtab	0.24	0.00	0.28	1.00	0.03	0.27
	Aghabalaaei	Sama	0.24	0.20	0.40	0.80	0.17	0.37
	Ahmadi	Ghazaleh	0.11	0.33	0.19	0.67	0.10	0.20
	Aliasgari	Fatemeh	0.14	0.50	0.18	0.50	0.07	0.20
	Amiri	Sara	0.08	0.60	0.16	0.40	0.17	0.23
	Banaei	Hanieh	0.30	0.67	0.33	0.33	0.10	0.37
	Charati	Motahareh	0.29	0.50	0.32	0.50	0.07	0.33
	Ebrahimi	Sana	0.00	0.33	0.17	0.67	0.20	0.20
	Fallah Alipo	Zeinab	0.24	0.60	0.32	0.40	0.17	0.37
	Hozhabri	Kimiya	0.33	0.33	0.50	0.67	0.20	0.47
	Khani	Aatefeh	0.48	0.71	0.57	0.29	0.23	0.60
	Metochi	Ida	0.39	1.00	0.39	0.00	0.07	0.43
	Mohammadi	Maedeh	0.46	1.00	0.46	0.00	0.07	0.50
	Moousavi	Sara	0.08	0.50	0.15	0.50	0.13	0.20
	Moustofi	Delaram	0.24	0.60	0.32	0.40	0.17	0.37
	Naderi	Shirin	0.34	0.00	0.38	1.00	0.03	0.37

Pretest= 13% ± 7% s.d.

Posttest= 34% ± 12% s.d.

Hgain=24% ± 15% s.d. (pretested incorrectly and posted correctly)

Dloss=54% ± 29% s.d. (correctly pretested but incorrectly post tested it), (+, -)

Dgain=32% ± 13% s.d. (incorrectly pretested and posted it correctly), (-, +)

R=46% ± 29% s.d. (both pre and posttest problems), (+, +)

In analysis columns in Table 4.5.these new calculations for each student in control group and in Table 4.6.for average of the class are included. Analysis for control group by Excel shows (Figure 4.8) pretest, posttest, Hgain, Dgain, Dloss, Retention (R) and standard deviation of them for each student and average of the class.

Table 4.5. FCI results for individual students in control group.

	FCI results							
	Last	**First**	**Hgain%**	**R%**	**Dgain%**	**Dloss%**	**Pre%**	**Post%**
1	Abbasi	Zahra	4	0	24	100	17	20
2	Abbasipour	Maryam	8	60	16	40	17	23
3	Amoohasan	Sara	4	33	21	67	20	23
4	Anisheh	Samaaneh	8	60	16	40	17	23
5	Bamdadiyan	Mehrnoush	3	0	7	100	3	7
6	Chegini	Nastaran	9	43	26	57	23	30
7	Ebrahimi	Aarefeh	4	0	15	100	10	13
8	Ghoreishi	Zeinab	8	0	23	100	13	20
9	Golig	Fatemeh	7	0	19	100	10	17
10	Hesaaraki	Faaezah	15	75	19	25	13	27
11	Kazemi	Mobina	7	0	10	100	3	10
12	Majidi	Kimiya	4	50	12	50	13	17
13	Maleki	Farzaneh	4	0	24	100	17	20
14	Naseri	Fatemeh	11	33	19	67	10	20
15	Pakaavar	Aysan	4	0	29	100	20	23
16	Rahimi	Hanieh	0	17	21	83	20	20
17	Salehi	Farnoush	4	0	19	100	13	17
18	Same	Zeinab	8	50	15	50	13	20
19	Soleymani	Marjan	0	33	17	67	20	20
20	Tahoori	Farzaneh	28	40	40	60	17	40

Table 4.6. Class average Hgain, Dgain, Dloss, Retention, pretest, posttest for controll group.

FCI results for class							
Control Group		**Hgain%**	**R%**	**Dgain%**	**Dloss%**	**Pre%**	**Post%**
	ClassAv	7	25	20	75	15	21
	St. Dev.	6	26	7	26	5	7
	Count	20	20	20	20	20	20

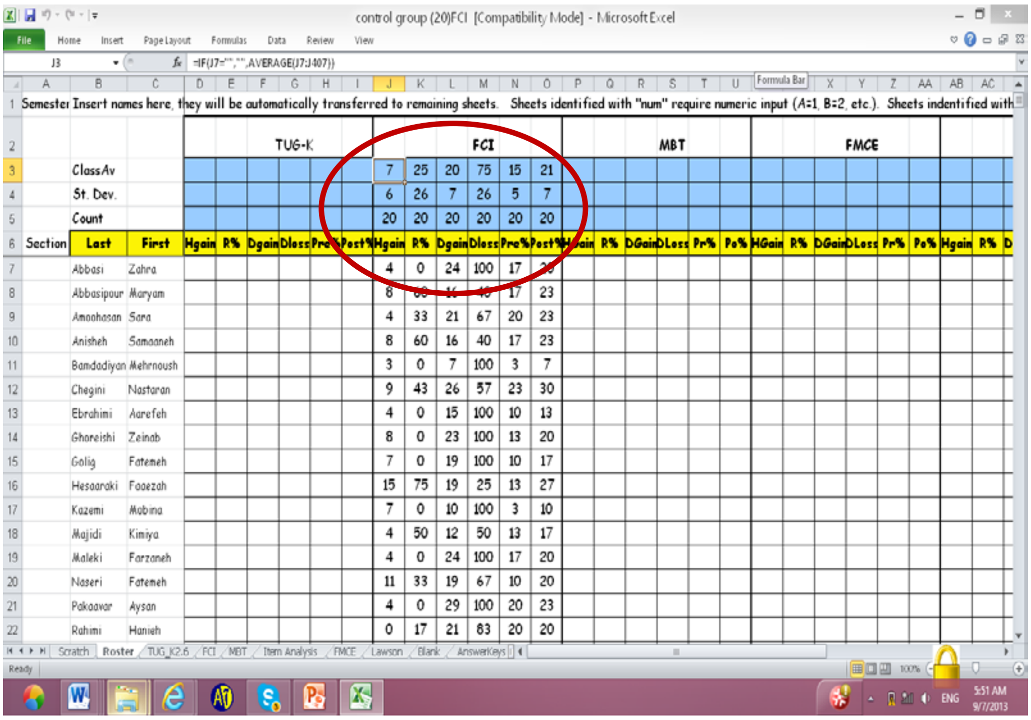


Figure 4.8. The analyzing data of control group (ICI)

Pretest= 15% ± 5% s.d.

Posttest=21% ± 7% s.d.

Hgain=7% ± 6% s.d. (pretested incorrectly and posted correctly)

Dloss=75% ± 26% s.d. (correctly pretested but incorrectly post tested it), (+, -)

Dgain=20% ± 7% s.d. (incorrectly pretested and posted it correctly), (-, +)

R=25% ± 26% s.d. (both pre and posttest problems), (+, +)

Richard Hake found that for Interactive Engagement (IE) and Traditional (T) introductory mechanics courses: the normalized gain for IE courses was $\langle Hgain \rangle_{IE} = 0.48 \pm 0.14$sd.

That is over twice the gain for traditionally taught courses: $\langle Hgain \rangle_{T} = 0.23 \pm 0.04$sd.

Jeff Saul and Edward "Joe" Redish found that for traditionally taught college algebra-based and calculus-based physics courses, <Hgain> are typically 0.2.The definition for Hgain levels is follow:

(a) "High-g" courses as those with (<Hgain>) > 0.7;

(b) "Medium-g" courses as those with 0.7 > (<Hgain>) > 0.3;

(c) "Low-g" courses as those with (<Hgain>) < 0.3 (Hake, 1998).

In this study we found that for traditionally taught 10th grade high school physics course, Hgain is typically 0.07 and for ICI method for experimental group, Hgain is typically 0.24 (much lower than in Hake's article). Remember: these students are only the 20% or so of the class that are "good at math", but the improvement in Hgain from traditional method to ICI is high. This is over triple the gain for traditionally taught course.

Average Hgain reported here suggests that the Interactive Conceptual Instruction approach was very successful in promoting learning. Furthermore, we are aware of the difference between the learning Hgains achieved through ICI and those achieved through earlier more traditional approaches to teaching, but is it a sign for a course to be effective more than other? Depending on Dellwo (2010) explanation it is not a complete sign for being successful in a course by itself. So the average values of Dgain and γ Dloss for traditional and ICI courses are determined. Although the research Hgain results adopted does not permit direct comparisons in learning gains between matched control and experimental classes subjected to ‘new’ and ‘traditional’ teaching, we believe that comparisons with FCI data gathered in research studies internationally allow us to claim relative success for the ICI teaching approach in Dellwo's idea. In the next part we will calculate the reported Dellwo's components to give more satisfactions in result.

Table 4.7. Results for both groups.

	Pretest	posttest	Hgain	Dgain	Dloss	Ret	γ	γ.Dloss
Experi group	0.13	0.34	0.24	0.32	0.54	0.46	0.149	0.084
Contr group	0.15	0.21	0.07	0.20	0.75	0.25	0.176	0.132

It is important to consider differences in student populations when comparing the normalized gains of different classes. For example, it might be incorrect to conclude that teaching methods used in an active teaching class with a normalized gain of 0.6 are necessarily more effective than those that produce a gain of 0.3 in a different class. The backgrounds of the students in the two classes could be a more important factor than the specific methods used in the classes (Coletta and Phillips, 2005). The probability of guessing correct answers for the FCI questions for both groups (13% for experimental and 15% for control group) in pretest are about 14%. It can therefore be concluded that the students’ initial knowledge and understanding of mechanics was very poor and they are the same. This was by no means a surprise because the students had received only limited instruction in mechanics in lower secondary school. Successive differences in nominal values of Hgain listed in Table 4.7 quantify the added effectiveness. For example, the value 0.54 for the Dloss in ICI group means that 54% of diagnostic questions answered correctly on pretest were answered incorrectly on posttest and the value 0.32 for the Dgain means that 32% of diagnostic questions answered incorrectly on pretest were answered correctly on posttest. In addition data in Table 4.7 indicates that indicates that Dloss decreased from traditional instructional method to the ICI, and also renormalized gain decreased with γDloss = 0.084. Although nominal values of γL from traditional method to ICI decreased slightly, the increase in Dgain is large enough to be statistically significant.

In previous chapter was discussed that "The course with the larger value of normalized gain (Dgain) and smaller value of renormalized loss (γ.Dloss) is the more effective course" in algebraic form. It does not mean by "The course with the larger value of normalized change (Hgain) is the more effective course."

If A is a more effective course than B in the sense of (3.6.a), then G_A- G_B is a value-added measure of improved effectiveness due to larger gains. Also, γ is a value-added measure of improved effectiveness due to smaller renormalized losses experienced by students in the more effective course. Consequently,

$$g_A - g_B = (G_A - G_B) + (\gamma_B L_B - \gamma_A L_A) \quad : \text{ Referring to (3.7)}$$

is a value-added measure of the total improvement in effectiveness when equivalently "The course with the larger value of normalized gain (Dgain) and smaller value of renormalized loss (γ.Dloss) is the more effective course" applies and one course can claim the larger gains as well as the smaller renormalized losses. So,

$$g_{(exp)} - g_{(cont)} = (\text{Dgain}_{(exp)} - \text{Dgain}_{(cont)}) + (\gamma.\text{Dloss}_{(cont)} - \gamma.\text{Dloss}_{(exp)})$$
$$= (0.32-0.20) + (0.132 - 0.084) = 0.168$$

Inspection of Table 4.7 reveals that Dgain was larger from traditional method to ICI. Also renormalized loss was smaller from traditional to ICI. Consequently, the experimental group was more effective in promoting learning ICI during the instructional periods than control group by an amount equal to the difference in $\Delta g = 0.168$. It shows the ICI course is more effective than traditional course.

Although Dellwo's gain points to the overall success of the teaching, these data do not provide information about specific learning difficulties that students may have encountered in coming to an understanding of the force concept. This issue is addressed in the next part.

4.5. Discussion: FCI Analyzing Items

It is interesting to compare the students' responses in two groups to FCI items, which focus on the pretest correct answers (%) (Figure 4.9) it seems a similarity between both groups in the area surrounded by red and blue lines and it shows both groups are the same level of knowledge before instruction. In Figure 4.10 there is a focus on percentage of correct answers of FCI items for both groups in posttest. It shows the percentages of correct answers to FCI items for experimental group in posttest is more developed than control group, the area surrounded by red line is larger than blue line. This comparison shows the effectiveness of ICI method to traditional method.

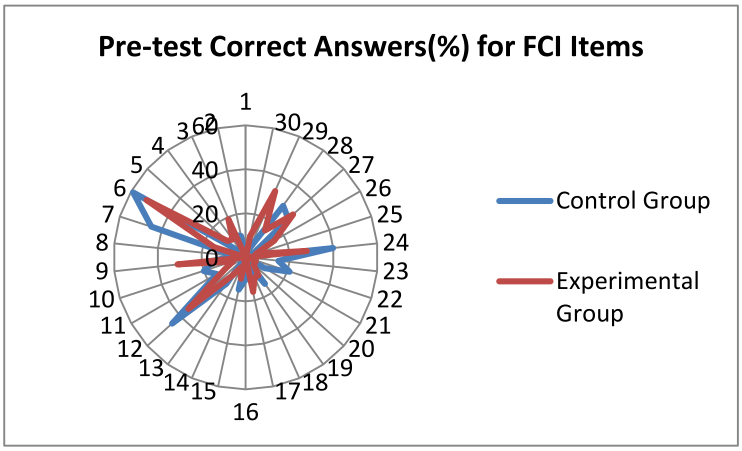


Figure 4.9. Pre-Test Correct Answers (%) of FCI Items for Control and Experimental groups.

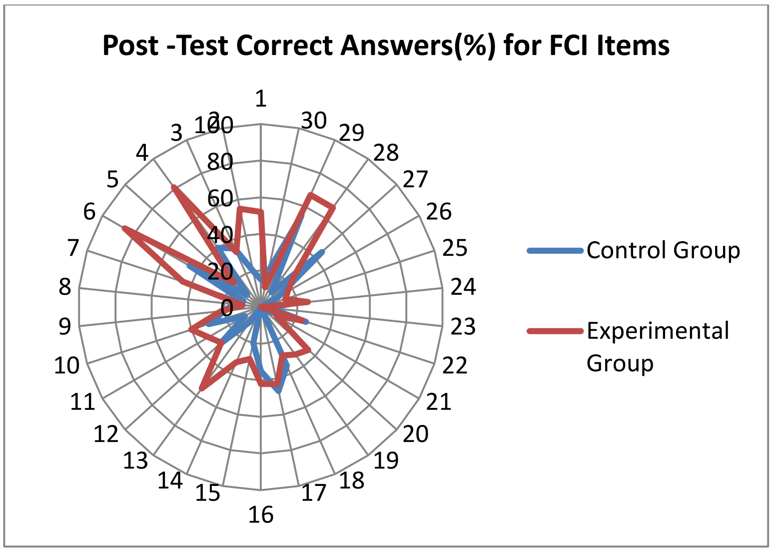


Figure 4.10. Post-Test Correct Answers(%) of FCI Items for Control and Experimental groups.

In Table 4.8.Pre and posttest correct answers (%) of FCI items for control and experimental group are shown. For example first item of FCI for control group is improved from 0(%) to 15(%), while for experimental group improvement is from 0(%) to 52(%).

Table 4.8. Pre and posttest correct answers (%) of FCI items for control and experimental group.

	Control Group		Experimental Group	
FCI Items	**Pre(%)**	**Post(%)**	**Pre(%)**	**Post(%)**
1	0	15	0	52
2	10	20	0	55
3	11	35	19	33
4	0	40	10	81
5	5	10	11	20
6	59	45	52	86
7	45	10	15	45
8	5	15	0	10
9	15	20	31	22
10	20	30	6	40
11	15	10	11	33
12	45	30	35	29
13	15	10	10	55
14	0	0	5	33
15	15	20	10	29
16	10	35	0	42
17	5	47	16	43
18	5	35	10	29

19	15	0	10	32
20	0	0	5	35
21	10	5	5	10
22	21	26	5	24
23	15	5	0	0
24	40	16	28	26
25	0	0	5	14
26	5	11	15	17
27	26	45	29	24
28	29	10	15	67
29	5	55	33	67
30	5	20	10	11

FCI consists of 30 items which are related to different parts of mechanics. There is a breakdown of FCI questions (Savinainen and Scott, 2002):

- Newton's Second Law free fall, no air resistance: Problems 1, 3, 13;
- Newton's Second Law (impulse): Problem 8;
- Newton's Second Law (a=0): Problem 9-11, 17, 23, 24, 25, 29;
- Newton's Second Law (a#0): Problem 21, 22, 26, 27, 29, 30;
- Circular motion or circular to linear motion: Problems 5-7, 18 ,
- Projectile motion: Problems 2, 12, 14;
- Newton's Third Law: Problems 4, 15, 16, 28;
- Constant and changing velocity particles (kinematics): 19, 20.

To gain a more detailed idea about how student responses changed after instruction for experimental group, the results are presented in Table 4.9.along the eight conceptual dimensions of the force concept probed in the FCI.

Table 4.9. Pre and post-test correct answers (%) of FCI dimensions for the experimental group.

Experimental Group			
FCI items	**FCI Conceptual Dimentions**	**Pre(%)**	**Post(%)**
6	N1,Circular motion	52	86
7	N1,Circular motion	15	45
29	N2	33	67
21	N2,a#0	5	10
22	N2,a#0	5	24
26	N2,a#0	15	17
27	N2,a#0	29	24

30	N2,a#0	10	11
9	N2,a=0	31	22
10	N2,a=0	6	40
11	N2,a=0	11	33
17	N2,a=0	16	43
23	N2,a=0	0	0
24	N2,a=0	28	26
25	N2,a=0	5	14
1	N2,Free fall	0	52
3	N2,Free fall	19	33
13	N2,Free fall	10	55
8	N2,Impulse	0	10
4	N3	10	81
15	N3	10	29
16	N3	0	42
28	N3	15	67
2	Projectile motion	0	55
12	Projectile motion	35	29
14	Projectile motion	5	33
5	Circular motion	11	20
18	Circular motion	10	29
19	Kinematics	10	32
20	Kinematics	5	35

To gain a more detailed idea about how student responses changed after instruction for experimental group, the results are presented in Figure 4.11 along the eight conceptual dimensions of the force concept probed in the FCI. These results indicate that the teaching was ineffective in relation to Newton’s Second Law when a#0 : Hake’s average gain was lower than 0.14.The students had problems with vectors knowledge before the mechanics course and this may partially explain their difficulties with these questions. This hypothesis gains support from the very low success rate with answers to question 30.

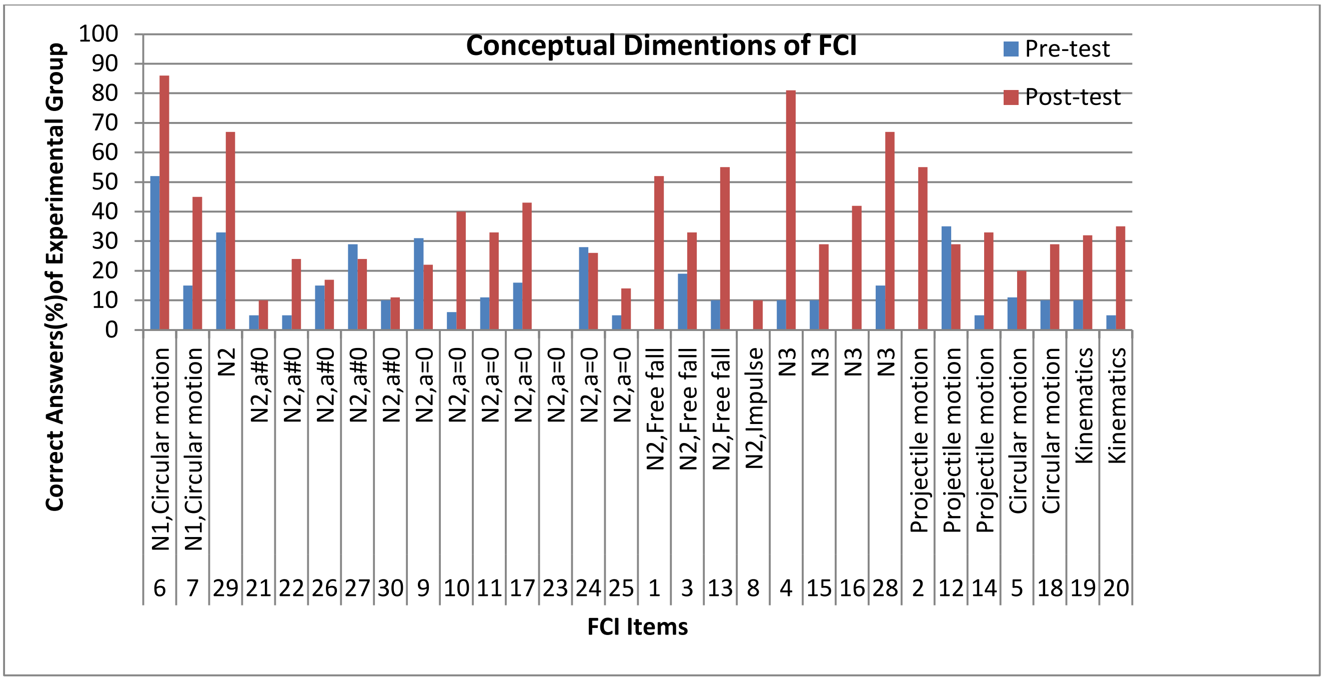


Figure 4.11. Pre and post-test correct answers (%) of FCI dimensions for the experimental group.

At the same time there were some questions (questions 6, 29, 1, 13, 28, 2 and 4) which were very well answered. These questions address differentiation between Newton's Laws concepts. Students made substantial gains along all the other dimensions, with improvements in performance to relating the items of 3, 7, 10, 11, 14, 15, 16, 17, 18, 19, 20 and 22 being particularly impressive. To investigate the benefit of MRA and ICI method on students understanding and analyzing, Table 4.10. shows some activities and related FCI concept which improved to high level. The most important similarity between activities which help to gain students understanding is being demonstration or video in MRA.

Table 4.10. Developed Items for Experimental Group and Related Research Activities.

FCI Item	FCI Concept	Related Research Activities
6	NL1,Circular motion	1(demonstration),9(video),10(video)
29	NL2	2(conceptual problem),3(video),8(demonstration)
1	NL2 Free fall	5(demonstration)
13	NL2 Free fall	5(demonstration)
4	NL3	4(video),6(demonstration),7(video), 8(demonstration)
28	NL3	4(video),6(demonstration),7(video)
2	Projectile Motion	5(demonstration)

CHAPTER 5

Limitations, conclusions and implications

This Chapter contains three sections. The first section: Limitations, considers those factors or conditions that may influence the confidence with which the conclusions can be stated and the generalizability of the findings. The second section: Conclusion, deals with the general answers to the research question. The last section: Implications, provides some suggestions for improving the teaching and learning of physics in high schools; and for further studies in this field.

5.1. Limitations

Classical Newtonian mechanics has traditionally been the first subject taught in both high school and undergraduate physics courses. Therefore, most of the new educational projects and curricula, as well as physics education research and the standard tests, focused on mechanics. Newton’s laws of motion are especially important when viewed in conjunction with other fundamental concepts in physics. The majority of research about force is designed to detect student misconceptions or alternative conceptions. These studies show that there are a considerable number of alternative conceptions related to Newton’s laws among primary, secondary and university students. Some research has also demonstrated that such misconceptions also existed among pre-service teachers as well as teachers (Kikas, 2004; Trumper, 2003). Interestingly, there has been limited number of studies about how to replace these misconceptions. Consequently, studies that attempt to replace such misconceptions have become increasingly important. For example, in this study we probe some misconceptions in control groups which are detected among comparing Retention in pre and posttest. Pretest for experimental group is 0.13 and Retention is 0.46.It shows 0.13 of FCI scores was correct in pretest, but only 0.46 of them are answered correctly in posttest. For control group the pretest is 0.15 and Retention is 0.25. It shows for control group which was under traditional instruction in formal teaching the pretest score is more than experimental group and it means the students in control group have more conceptual knowledge than experimental group, but unfortunately they answer only 0.25 of correct answer in pretest, correctly in posttest. It indicates that traditional method for both groups has negative effects. Remembering ICI group was undertaking a traditional instruction with ICI. Traditional teaching could effect on ICI group negatively. To erase these misconceptions from students' mind it needs a lot of activities and demonstrations and videos which lack of instruction time and curriculum and conceptual text book made this study problematic. Limitation of applying new method in high schools is an important obstacle, resistance of manager and formal teacher and students is some of them. For students' resistance against teamwork and social educational culture, and their low motivation which is determined by final exam in the end of semester is considerable. Negative attitudes toward student ratings are especially resistance to change, and it seems that administrators support their belief in student-rating myths with personal and anecdotal evidence. To search for better and fairer means of evaluating teaching effectiveness and providing better bases for reappraisal of ICI teaching, we need to experiment with alternative methods of soliciting students' opinions**.** Hidden variables that might influence FCI gain' s e.g., the gender (This study is about high school girls some researches have reported that males achieved larger Hgain than females for some classes[5]), math proficiency, spatial visualization ability, completion of high-school physics courses, scientific reasoning skills, physics aptitude, personality type, motivation, socio-economic level, and curriculum were the other limitations. Lack of appropriate instruments to use interactive conceptual instruction like computer and lack of instruction time are the other limitation in this study.

5.2. Conclusions

Investigating the students' ability to analyze mechanics situation requires measurement of students' learning in Newton's Laws in high school and college classrooms. Course exams and final grades typically measures lower-level educational objectives such as memory of facts and definitions rather than higher-level outcomes such as critical thinking and problem solving. The traditional mode of introductory physics instruction (passive student lectures, recipe labs, and algorithmic problem exams) is relatively ineffective in promoting students' conceptual understanding, even when employed by teachers who receive relatively high student evaluations. In this study we have examined how students are being able to analyze mechanics situation using Newton's Laws. The suggestion is with the help of ICI method and MRA, teachers can improve students' abilities to analyze environment.

I believe that the increased learning gains can be linked to three aspects of the associated pedagogy: the use of interactive approaches where an ongoing dialogue between teacher and students focuses on development of conceptual understandings and where the students have time and opportunity to talk through their developing understandings, with the support of the teacher, and the use of teaching strategy, such as ISLE to plan multiple representation activities (MRA) and use of them in ICI teaching method.

Interactive Conceptual Instruction entails four features or components, which overlap with each other to some extent: Conceptual focus, Classroom interactions, Research-based materials, Use of texts. The ICI approach would offer the potential to promote enhanced learning gains in conceptual understanding of mechanics. To investigate the effects of ICI method it needs a strong instrument for measuring students' improvement. To probe students' ability we suggest using FCI to measure the effectiveness of alternative interactive conceptual instruction[6]. We examined class average FCI scores of 21 students in an interactive conceptual instruction (ICI) class. The method used to quantify changes in performance is a definitive feature of any pre/post testing design. Average Hgain reported here suggests that ICI approach was very successful in promoting learning. In addition we examined Dgain and Dloss and Retention on the force concept inventory (FCI) and found a significant improvement in gains. The improvement in the Hgain and Dgain in this research shows that planning activities based on MRA, for example demonstration and video related to real world and expressing the idea in different representations is very important to analyze mechanics situations and understanding Newton's Laws. The results show, the experimental group was more effective in promoting learning ICI during the instructional periods than control group by an amount equal to the difference in $\Delta g = 0.168$. It shows the ICI course is more effective than traditional course.

It is important to use activities including analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others in teaching Newton's Laws. This specialized knowledge included selecting representations for particular purposes, recognizing what is involved in using a particular representation and linking representations to underlying ideas and other representations. In the other word understanding how to select an appropriate representation, how to construct an appropriate representation and how to relate representations is a way to help students to analyze mechanics situation. Results shows among different forms of representing, demonstrations and videos in multiple ways are the most important activities which help to gain students' understanding in Newton's Laws.

5.3. Implications

One of the significant tasks according to this study is learning reform by attaching the highest importance to learners. In particular, physics teaching and learning is in need of reform. Some aspects for the improvement of teaching and learning physics in high schools arise from the findings of this study. These are the improvement of the physics curriculum, improvement of teaching, and the development of classroom environment and opportunities for learning, and the supports for teaching and learning.

Some recommended actions to improve physics teaching and learning depends on findings of this research are presented.

- The development of physics teaching in high schools that started years ago in the ministry education's project should be continued and further promoted.
  Physics instructors believe that one of the motivations for studying physics is its application to real situations, and they wish their students to be able to apply physics. Students also expressed the view that physics is important to people’s lives and the development of technology, but, physics is difficult and complicated, they have low motivation for studying physics and they do not want to study physics. These findings imply that there are inconsistencies between an ideal physics curriculum and the implemented curriculum. Physics must be more relevant to everyday experiences and more applicable for students. The revision of the curriculum is the first step towards improvement of teaching and learning.
- Modern educational technology and innovation, for example computers and audio-visual facilities should be introduced and used broadly in physics classrooms. The high school physics classroom environment should be systematically studied in physical and instrumental aspects. Such studies would help to shape pedagogy so that more progressive approaches can be introduced in ways that are sensitive to high school students.
- Laboratory approaches to teaching and learning, and the strategies of teaching and learning by investigation and interactive forms of teaching should be promoted. Many students adopted surface passive approaches to learning and there is need for further research into strategies that assist students to be more active and metacognitive in their learning.
- Short-courses training or workshops on effective teaching in physics and other cooperative activities should proceed regularly among small groups of the instructors on a regional basis. It seems sometimes that the educational culture is an obstacle for students learning science and physics. The comparison between new methods in education and social culture for teaching and learning is therefore an interesting area to study. Effective ways of teaching and learning physics which are consistent with social culture should be developed.
- The high schools should encourage their instructors in developing more learning materials and new laboratory investigation tasks using simple and inexpensive equipment. Teachers need to be able to draw on a variety of representations as there is “no single most powerful forms of

representation flexibly and fluidly moving across multiple representations based on underlying principles. This study with no more expensive equipment proves the necessity of new methods in teaching and learning strategy.

- The improvement of teaching and learning physics would not succeed without appropriate supports. The two most important are administration and financial supports. This study shows efforts in physics education could help physics teachers to develop students understanding, so submitting this study to national workshops and seminars can gain more attention in administration and financial support.

This work scratches the surface; additional work needs to be done to develop a more complete understanding of students' concepts regarding Newton's Laws, to investigate other facets of the learning of Newton's Laws related to real life, and to produce and test materials in an effort to improve instruction. For the future work in this effort two recommended study are presented.

- 1-Plan other activities to increase students' abilities to analyze real world mechanics situation depending on the results of this research.
- 2-Investigate the effects of multiple representation activities on students understanding level and their understanding model in Newton's Laws.

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APPENDIX A

MULTIPLE REPRESENTATION ACTIVITIES

Activity 1-Demonstration : Doing in class

Try to pull a sheet of paper out from underneath a breaker of water without spilling any water. Pull out the tablecloth without spilling a drop. Try different volumes of water.

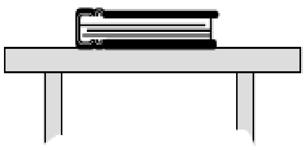
Activity 2- Doing in class

A book rests on a table.

(a) List and describe the forces that you think are acting on the book.

(b) Do you think the book is accelerating? Explain.

(c) Explain why the book does not fall.



Activity 3- Demonstration: Watching in class

On Rollerblades: Qualitative Observational Experiment-Video 1

Aim

To observe the motion of an object when it does not interact with other objects and when it does interact with other objects. (Friction between the floor and rollerblades is negligible.)

Description of the Experiment

Observe what is needed for Eugenia to start moving. Notice what happens when she interacts with other objects. Notice what happens when she does not interact with other objects.

Questions

- What was necessary for Eugenia to start moving? Consider the different ways in which she got moving. What did they have in common?
- What was necessary for Eugenia to keep moving?
- What did Eugenia have to do to stop moving?
- What can you say about Eugenia's speed after David pushed her once? How do you know? With respect to what observer did you make your statement? What observers would see Eugenia speeding up or slowing down after David pushed her? What observers would see her moving with constant velocity?
- Represent Eugenia' motion during the moment when David pushes her, after he pushed her (several instances) and when she stops using motion diagrams and force (free-body) diagrams. Find a pattern in those diagrams. How are the two diagrams for each instance related? What assumptions did you make?

Activity 4-Demonstration: Video 2-Watching in class

Pulling Eugenia on Rollerblades: Qualitative Observational Experiment

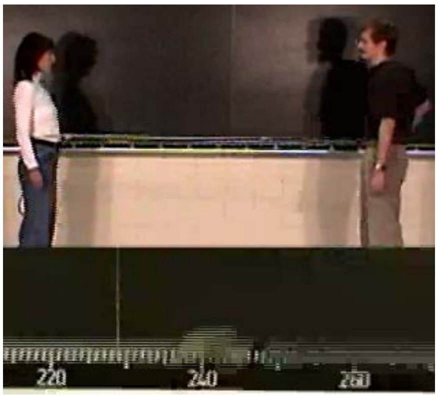
Aim

1. To observe the effect of a pull exerted on a person on rollerblades and the change in the person's motion.
2. To observe the effect of person's mass on her motion when she is pulled.

Description of the Experiment

Observe what happens to Eugenia when Dave stretches a spring attached to her waist. Notice what happens when the spring stretches more. What happens to Eugenia's motion after Dave has finished pulling?

How did putting on and taking off a backpack affect Eugenia's change in motion when Dave pulled her?



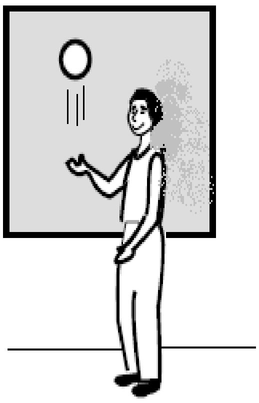
Questions

1. Draw motion diagrams for Eugenia as David is pulling her and after each pull is over.
2. Draw three force (free-body) diagrams for Eugenia for each f the pulls and two for after each pull is over.
3. What is the relationship between the motion diagrams and the force diagrams?

Suggest a possible relationship between Eugenia's change in motion and

1. how hard Dave pulled her, and
2. her mass.

Activity 5- Doing in class



A ball is thrown straight up. Consider the ball while it is in the air (after it is released).

(a) List and describe the forces that you think are acting on the ball.

(b) Do you think the ball is accelerating? If so, during which parts of its motion is it accelerating? Explain.

(c) Explain why the ball moves upward and then moves downward.

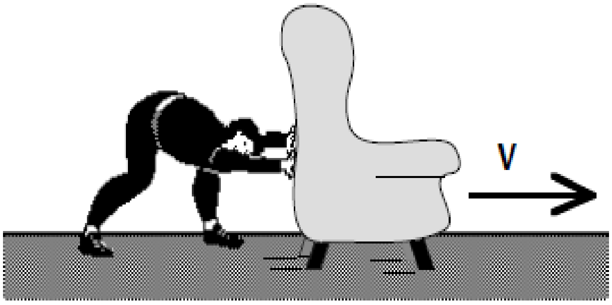
Activity 6- Doing in class

A chair is pushed across the floor at constant speed. Consider only when the chair is in motion.

(a) List and describe the forces that you think are acting on the chair.

(b) Do you think the chair is accelerating? Explain.

(c) Explain why the chair is moving at constant speed.



Activity 7-Demonstration: Video 3-Watching in class

Eugenia and David push on each other: Observational Experiment

Aim

To construct a relation/rule relating the force Eugenia exerts on David and the force David exerts on Eugenia when either one of them pushes the other.

Description of the Experiment

- Carefully observe what happens when David pushes Eugenia and Eugenia pushes David.
- Does it seem possible for David to push Eugenia without starting to move himself? Does it seem possible for Eugenia to push David without starting to move herself?

Addtional Information

Eugenia's mass with gear:	52kg
David's mass with gear:	83kg

Questions

For one particular trial when either David pushes or Eugenia pushes:

- Decide what you need to measure to determine the speed of Eugenia and the speed of David after the push is over?
- After the speeds have been determined, can you find the acceleration of David and the acceleration of Eugenia during the time interval when they are pushing each other?
- What assumptions should you make in order to find their accelerations?
- Use the information you have found and previously established relation between acceleration and force to compare the forces they exert on each other.
- Repeat for the other trials
- What can you conclude about the strength of the push of David on Eugenia as compared to Eugenia's push when Eugenia pushes David?
- What can you conclude about the strength of the push of Eugenia on David as compared to David's push when David pushes Eugenia?

Activity 8- Doing in class

List and describe the forces that you think are acting on each subject

Activity 9- Demonstration: Video 4-Watching in class

Ball constrained to a ring: Qualitative Testing Experiment

Aim

To test the necessary conditions for circular motion at constant speed.

Description of the Experiment

A wooden ball is placed inside a large metal ring placed on a flat surface, and set in motion inside of the ring. Part of the ring can be removed, making a gap and allowing the ball to escape from the ring.

Use your understanding of circular motion to predict what the path of the ball will be after it reaches the gap.

1. Explain your prediction, make sure it is based on what you learned from the previous experiments.
2. What other models do you need to use/assume to predict the path of the ball after it exits the ring?

Questions

Now that you have watched the video, did your prediction agree with what you observed? If your prediction did not match the outcome of the experiment, decide how you need to change your reasoning that led to the prediction to explain what you see.

Activity 10 –Demonstration : Video 5-Watching in class

David and Alan hit a ball so that it travels in a circle: Observational Experiment

Aim

To find a pattern in the direction of the vector sum of the forces exerted by other objects on an object moving in a circle at constant speed.

Description of the Experiment

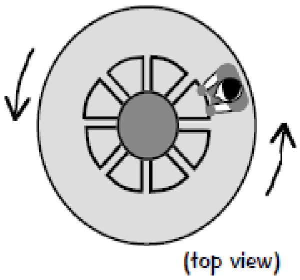
In the first video David hits a ball with a mallet so that it travels in a circle. Observe how he is hitting the ball.

In the second video, Alan hits a ball with a stick so that it travels in a circle. Observe how he is hitting the ball.

Questions

- How is David hitting the ball (direction)? How is Alan hitting the ball?
- What are the objects that interact with the ball in each of the experiments? Draw a force (free-body) diagram for the ball at any point of its path for both experiments.
- When an object moves in a circle, is its velocity changing? Assume that the speed of the bowling ball remains almost constant and find the direction of the acceleration of the ball assuming that the direction of the acceleration is the same as the direction of the velocity change vector.
- Choose three positions on the ball's path and repeat a force (free-body diagram) for the ball. Do you see a pattern in the direction of the sum of the forces exerted on the ball?

Activity 11- Doing in class



A child is riding on a merry-go-round that is spinning very quickly at a constant rate.

(a) List and describe the forces that you think are acting on the child.

(b) Do you think the child is accelerating? Explain.

(c) Explain why the child is moving in a circle.

APPENDIX B

Force Concept Inventory

The Force Concept Inventory (FCI) is a multiple-choice "test" designed to assess student understanding of the most basic concepts in Newtonian mechanics. The FCI can be used for several purposes, but the most important one is to evaluate the effectiveness of instruction. For a full understanding of what has gone into development of this instrument and how it can be used, the FCI papers (Hestenes and Wells and Swackhamer, 1992 and Hestenes and

Halloun,1995) should be consulted, as well as: (a) the papers on the FCI predecessor, the Mechanics Diagnostic Test (Halloun and Hestenes,1985), (b) the paper on the Mechanics Baseline Test (Hestenes and Wells, 1992), which is recommended as an FCI companion test for assessing quantitative problem solving skills, and (c) Richard Hake's paper (Hake, 1998) on data collection on university and high school physics taught by many different teachers and methods.

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   (A) about half as long for the heavier ball as for the lighter one.
   (B) about half as long for the lighter ball as for the heavier one.
   (C) about the same for both balls.
   (D) considerably less for the heavier ball, but not necessarily half as long.
   (E) considerably less for the lighter ball, but not necessarily half as long.

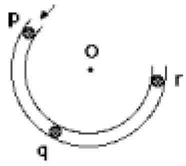
2. The two metal balls of the previous problem roll off a horizontal table with the same speed. In this situation:
   (A) both balls hit the floor at approximately the same horizontal distance from the base of the table.
   (B) the heavier ball hits the floor at about half the horizontal distance from the base of the table than does the lighter ball.
   (C) the lighter ball hits the floor at about half the horizontal distance from the base of the table than does the heavier ball.
   (D) the heavier ball hits the floor considerably closer to the base of the table than the lighter ball, but not necessarily at half the horizontal distance.
   (E) the lighter ball hits the floor considerably closer to the base of the table than the heavier ball, but not necessarily at half the horizontal distance.

3. A stone dropped from the roof of a single story building to the surface of the earth:
   (A) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
   (B) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth.
   (C) speeds up because of an almost constant force of gravity acting upon it.
   (D) falls because of the natural tendency of all objects to rest on the surface of the earth.
   (E) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

4. A large truck collides head-on with a small compact car. During the collision:
   (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
   (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
   (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   (D) the truck exerts a force on the car but the car does not exert a force on the truck.
   (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (5 and 6).

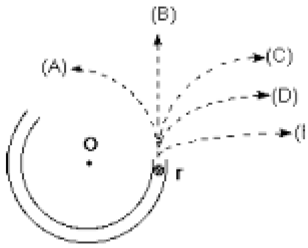
The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at "O". The channel has been anchored to a frictionless horizontal table top. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed into the channel at "p" and exits at "r."



5. Consider the following distinct forces:
   1. A downward force of gravity.
   2. A force exerted by the channel pointing from q to O.
   3. A force in the direction of motion.
   4. A force pointing from O to q.

   Which of the above forces is (are) acting on the ball when it is within the frictionless channel at position "q"?

   (A) 1 only.
   (B) 1 and 2.
   (C) 1 and 3.
   (D) 1, 2, and 3.
   (E) 1, 3, and 4.

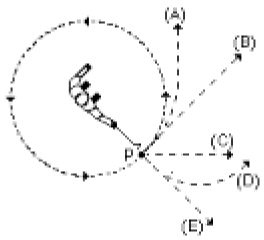


6. Which path in the figure at right would the ball most closely follow after it exits the channel at "r" and moves across the frictionless table top?

7. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.

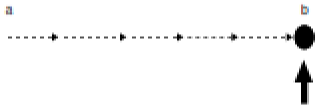
   At the point P indicated in the figure, the string suddenly breaks near the ball.

   If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

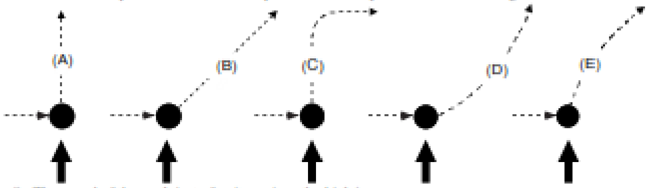


USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (8 through 11).

The figure depicts a hockey puck sliding with constant speed v_o in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with a speed v_k in the direction of the kick.



8. Which of the paths below would the puck most closely follow after receiving the kick ?

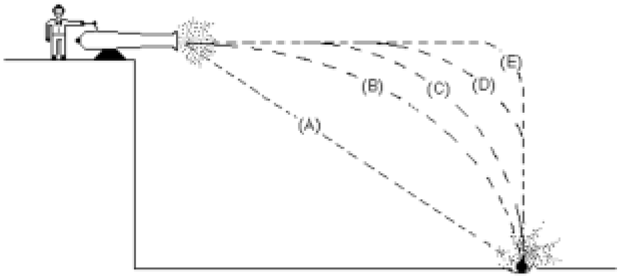


9. The speed of the puck just after it receives the kick is:
   (A) equal to the speed "v_o" it had before it received the kick.
   (B) equal to the speed "v_k" resulting from the kick and independent of the speed "v_o".
   (C) equal to the arithmetic sum of the speeds "v_o" and "v_k".
   (D) smaller than either of the speeds "v_o" or "v_k".
   (E) greater than either of the speeds "v_o" or "v_k", but less than the arithmetic sum of these two speeds.

10. Along the frictionless path you have chosen in question 8, the speed of the puck after receiving the kick:
   (A) is constant.
   (B) continuously increases.
   (C) continuously decreases.
   (D) increases for a while and decreases thereafter.
   (E) is constant for a while and decreases thereafter.

11. Along the frictionless path you have chosen in question 8, the main force(s) acting on the puck after receiving the kick is (are):
   (A) a downward force of gravity.
   (B) a downward force of gravity, and a horizontal force in the direction of motion.
   (C) a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
   (D) a downward force of gravity and an upward force exerted by the surface.
   (E) none. (No forces act on the puck.)

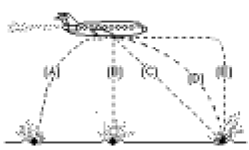
12. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?



13. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are):
    (A) a downward force of gravity along with a steadily decreasing upward force.
    (B) a steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the object gets closer to the earth.
    (C) an almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only a constant downward force of gravity.
    (D) an almost constant downward force of gravity only.
    (E) none of the above. The ball falls back to ground because of its natural tendency to rest on the surface of the earth.

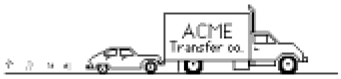
14. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

    As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?



USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (15 and 16).

A large truck breaks down out on the road and receives a push back into town by a small compact car as shown in the figure below.



15. While the car, still pushing the truck, is speeding up to get up to cruising speed:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
    (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

16. After the car reaches the constant cruising speed at which its driver wishes to push the truck:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot push back against the car. The truck is pushed forward simply because it is in the way of the car.
    (E) neither the car nor the truck exert any force on the other. The truck is pushed forward simply because it is in the way of the car.

17. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:

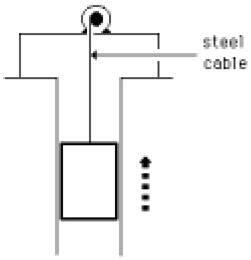
(A) the upward force by the cable is greater than the downward force of gravity.

(B) the upward force by the cable is equal to the downward force of gravity.

(C) the upward force by the cable is smaller than the downward force of gravity.

(D) the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.

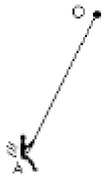
(E) none of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).



Elevator going up
at constant speed

18. The figure below shows a boy swinging on a rope, starting at a point higher than A. Consider the following distinct forces:

1. A downward force of gravity.
2. A force exerted by the rope pointing from A to O.
3. A force in the direction of the boy's motion.
4. A force pointing from O to A.



Which of the above forces is (are) acting on the boy when he is at position A?

(A) 1 only.

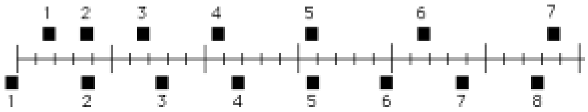
(B) 1 and 2.

(C) 1 and 3.

(D) 1, 2, and 3.

(E) 1, 3, and 4.

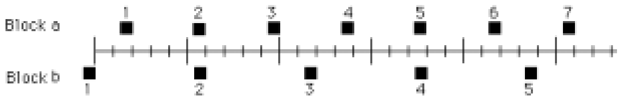
19. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



Do the blocks ever have the same speed?

(A) No.
(B) Yes, at instant 2.
(C) Yes, at instant 5.
(D) Yes, at instants 2 and 5.
(E) Yes, at some time during the interval 3 to 4.

20. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



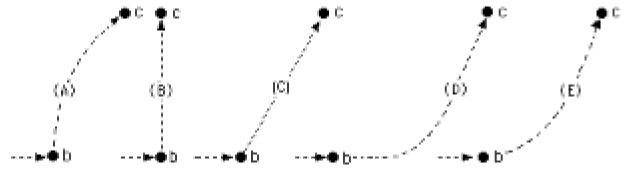
The accelerations of the blocks are related as follows:

(A) The acceleration of "a" is greater than the acceleration of " b".
(B) The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.
(C) The acceleration of "b" is greater than the acceleration of "a".
(D) The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.
(E) Not enough information is given to answer the question.

USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (21 through 24).

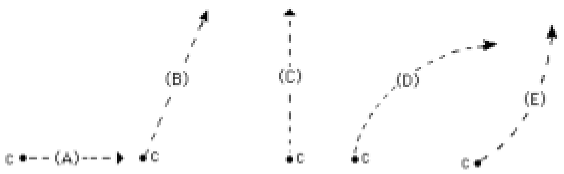
A rocket drifts sideways in outer space from point "a" to point "b" as shown below. The rocket is subject to no outside forces. Starting at position "b", the rocket's engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line "ab". The constant thrust is maintained until the rocket reaches a point "c" in space.

21. Which of the paths below best represents the path of the rocket between points "b" and "c"?



22. As the rocket moves from position"b" to position "c" its speed is:
   (A) constant.
   (B) continuously increasing.
   (C) continuously decreasing.
   (D) increasing for a while and constant thereafter.
   (E) constant for a while and decreasing thereafter.

23. At point "c" the rocket's engine is turned off and the thrust immediately drops to zero. Which of the paths below will the rocket follow beyond point "c"?



24. Beyond position "c" the speed of the rocket is:
   (A) constant.
   (B) continuously increasing.
   (C) continuously decreasing.
   (D) increasing for a while and constant thereafter.
   (E) constant for a while and decreasing thereafter.

25. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed "v_o".

The constant horizontal force applied by the woman:

(A) has the same magnitude as the weight of the box.
(B) is greater than the weight of the box.
(C) has the same magnitude as the total force which resists the motion of the box.
(D) is greater than the total force which resists the motion of the box.
(E) is greater than either the weight of the box or the total force which resists its motion.

26. If the woman in the previous question doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves:

(A) with a constant speed that is double the speed "v_o" in the previous question.
(B) with a constant speed that is greater than the speed "v_o" in the previous question, but not necessarily twice as great.
(C) for a while with a speed that is constant and greater than the speed "v_o" in the previous question, then with a speed that increases thereafter.
(D) for a while with an increasing speed, then with a constant speed thereafter.
(E) with a continuously increasing speed.

27. If the woman in question 25 suddenly stops applying a horizontal force to the box, then the box will:

(A) immediately come to a stop.
(B) continue moving at a constant speed for a while and then slow to a stop.
(C) immediately start slowing to a stop.
(D) continue at a constant speed.
(E) increase its speed for a while and then start slowing to a stop.

28. In the figure at right, student "a" has a mass of 95 kg and student "b" has a mass of 77 kg. They sit in identical office chairs facing each other.

Student "a" places his bare feet on the knees of student "b", as shown. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.

During the push and while the students are still touching one another:

(A) neither student exerts a force on the other.
(B) student "a" exerts a force on student "b", but "b" does not exert any force on "a".
(C) each student exerts a force on the other, but "b" exerts the larger force.
(D) each student exerts a force on the other, but "a" exerts the larger force.
(E) each student exerts the same amount of force on the other.

29. An empty office chair is at rest on a floor. Consider the following forces:

1. A downward force of gravity.
2. An upward force exerted by the floor.
3. A net downward force exerted by the air.

Which of the forces is (are) acting on the office chair?
(A) 1 only.
(B) 1 and 2.
(C) 2 and 3.
(D) 1, 2, and 3.
(E) none of the forces. (Since the chair is at rest there are no forces acting upon it.)

30. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent's court.
Consider the following forces:

1. A downward force of gravity.
2. A force by the "hit".
3. A force exerted by the air.

Which of the above forces is (are) acting on the tennis ball after it has left contact with the racquet and before it touches the ground?
(A) 1 only.
(B) 1 and 2.
(C) 1 and 3.
(D) 2 and 3.
(E) 1, 2, and 3.