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HIGH SCHOOL STUDENTS' UNDERSTANDING OF INERTIAL AND NON-INERTIAL REFERENCE FRAMES

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High school students' understanding of inertial and non-inertial reference frames

Ece Güneysu

March 2021

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Arts in Curriculum and Instruction.

Assoc. Prof. Dr. Erdat Çataloğlu (Supervisor)

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ABSTRACT

HIGH SCHOOL STUDENTS' UNDERSTANDING OF INERTIAL AND NON-INERTIAL REFERENCE FRAMES

Ece Güneysu

M.A. in Curriculum and Instruction

Supervisor: Assoc. Prof. Dr. Erdat Çataloğlu

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The purpose of this study was to investigate high school students understanding of inertial and non-inertial reference frames. To this end the study used a test that was composed of two parts A and B. Part A consisted of 7 open-ended and part B 12 force multiple choice test questions. After obtaining the necessary permissions from the Ministry of Education, Turkey, the test was applied to a total of 301 9^{th}, 10^{th} and 12^{th} grade high-students in 2019. The female and male ratio were balanced and resembled the Turkish national distribution. After data collection, the first step was to determine the categories based on the student responses of the open-ended questions. As a result of these procedure 40 categories were determined. Then OLAP Cube procedures were used to obtain descriptive statistics on the 40 emerged categories. Classical item analysis was conducted on the force multiple choice part of the test. The Cronbach alpha value was found to be 0.53 and the test was classified as difficult. As a result of the analyses, we determined four major student understanding difficulties. These were labeled as In a lab/ground frame versus no frame/relativity, rotating versus steady objects, rotating frame and Newton's law.

Keywords: Reference frames, inertia, high school students understanding, rotating objects, Newton's first law

ÖZET

LİSE SEVİYESİNDEKİ ÖĞRENCİLERİN EYLEMLİ VE EYLEMSİZ REFERANS ÇERÇEVELERİNİ ANLAMALARI

Ece Güneysu

Yüksek Lisans, Eğitim Programları ve Öğretim

Tez Yöneticisi: Doç. Dr. Erdat Çataloğlu

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Bu çalışmanın amacı, lise öğrencilerinin eylemli ve eylemsiz referans çerçevelerini anlamalarını incelemektir. Bu amaçla, çalışmada A ve B olmak üzere iki bölümden oluşan bir test kullanılmıştır. Bölüm A'da 7 açık uçlu, bölüm B'de ise 12 çoktan seçmeli test sorusu yer almaktadır. Türkiye Milli Eğitim Bakanlığı'ndan gerekli izinler alındıktan sonra test 2019 yılında 9., 10. ve 12. sınıf olmak üzere toplam 301 lise öğrencisine uygulandı. Kadın ve erkek oranı dengelenmiş ve Türk ulusal dağılımına benziyordu. Veri toplandıktan sonra ilk adım, öğrenci yanıtlarına göre açık uçlu soruların kategorilerinin belirlenmesiydi. Bu işlem sonucunda 40 kategori belirlendi. Daha sonra, ortaya çıkan 40 kategori hakkında açıklayıcı istatistikler elde etmek için OLAP Cube prosedürleri kullanıldı. Testin kuvvet çoktan seçmeli kısmında klasik madde analizi yapılmıştır. Cronbach alfa değeri 0,53 olarak bulunmuş ve test zor olarak sınıflandırılmıştır. Analizler sonucunda, dört büyük öğrencinin anlama güçlüğü yaşadığını belirledik. Bunlar bir laboratuvarda / zemin çerçevesine karşı çerçeve/görelilik yok, dönen ve sabit nesneler, dönen çerçeve ve Newton yasası olarak belirlendi.

Anahtar kelimeler: Referans çerçeveleri, eylemsizlik, lise öğrencilerinin anlamaları, dönen cisimler, Newton'un birinci yasası

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CHAPTER 1: INTRODUCTION

Introduction

Learning difficulty is a general term developed to refer to some problems experienced in the process of information processing and difficulties experienced in learning. Learning difficulties are expressed as a problem that affects the brain's ability to receive, process, store and respond to information. Individuals with learning difficulties have problems about learning certain skills and have lower success than expected in some academic fields. Individuals with this difficulty may have problems in areas such as reading, writing, mathematics, speaking and listening skills, reasoning, remembering and organizing information (Rief & Stern, 2010).

The inconsistency between the low achievements of individuals with learning difficulties in one area and adequate achievements in other areas draws attention. When the learning difficulty is fully examined, it is seen that there are deficiencies in attention, perception, and language that affect not only cognition but also learning (Terry, 2012).

Physics is considered one of the most difficult areas of science by students. Because, physics includes experiments, formulas, calculations, graphs, and conceptual explanations concurrently.

The biggest reason why physics is hard or difficult to be understood by many students is that physics concepts contain abstract expressions. In this context, visual literacy is of great importance for students to make sense of the information they will gain in physics lessons. Transforming abstract concepts into vivid, meaningful known concrete concepts and making the learned information permanent is possible by visualizing them.

Students ' misconceptions and alternative concepts, inability to establish a relationship between the concepts of physics, inability to use the concept of physics learned in one subject in another, lack of problem solving skills, inability to use mathematical knowledge in physics, negative attitudes towards the course with lack of field knowledge are among the most important reasons for learning physics (Sabella & Redish, 2007).

Regardless of whether students encounter modern physics concepts in entry-level or advanced courses, it is very important to determine which subjects they fail in and whether they understand the concepts in depth as a result of the teaching. In addition, analyzing the relationships between the concepts that students learn and the concepts that they make sense by identifying with their daily lives can be useful for reasoning about teaching advanced subjects (Scher et al., 2001).

Students have difficulty understanding the subject in many areas of physics. Some topics such as mechanics, optics, astronomy, power, acceleration, velocity are very difficult to understand and explain, especially for children.

Many studies have been conducted in the literature on the difficulties that students experience in understanding these and similar branches of physics. Rimoldini and Singh (2005), in their study on rotation and rolling, investigated the difficulties created by students' concepts such as angular acceleration, moment of inertia, rotational kinetic energy, friction force and angular velocity, that may seem different to students in the first place. Barniol et al. (2013) conducted research on the difficulties experienced by students in learning the concept of torque.

In their study, Özcan and Tavukçuoğlu (2018) investigated the cognitive structures of high school students towards the concept of light and optics. Turkkan (2017) examined the cognitive structures of physics teacher candidates for the concept of electric field in his research.

In physics course, inertial and non-inertial frames are one of the most challenging subjects among students.

The terms in this topic are quite compelling and difficult to understand, not only for students, but also for adults. Perhaps it would not be wrong to say that this is the most compelling topic in physics.

In physics, a reference frame refers to a coordinate system used to determine and measure the properties of objects, such as position and orientation, over different time periods. It may also include sets of these properties used in representation. In a weaker sense, a frame of reference not only describes coordinates, but also describes the same three-dimensional spaces for each time frame in distinguishing objects moving in this system.

Frames of reference are divided into inertial and non-inertial. At this point, it is worth reviewing Newton's law of inertia. According to Newton, if an object is stationary and no force acts on it, that object continues to be stationary. Again, in this context, if an object makes a smooth linear motion (motion at a constant speed along a line), and no force acts on it, that object continues its smooth linear motion. This law, which has been considered true since Newton, is not always true. Because the accuracy of the law depends on which system of deployment it is spoken to.

If Newton's law of inertia is mentioned, it means that it is spoken according to a frame of reference in which this law applies. This type of reference frame is called an inertial reference frame. In other words, an inertial frame of reference is a coordinate system without acceleration. Thus, an inertial coordinate system is either constant or smooth linear motion relative to a place.

It can be considered whether such systems exist or not. If there is an inertial reference frame, an infinite system of inertial reference frames can be installed. Indeed, every frame of reference that moves smoothly linearly relative to the first system is an inertial system. A frame of reference in which the law of inertia does not apply is called an action frame of reference. These systems are systems with an acceleration relative to inertial systems.

Therefore, this study investigated high–school students understanding of inertial and a non-inertial reference frames. A free response test and the forced option test was used to gather students' way of thinking.

Background

Panse et al. (1994) claim that children are "active constructors of their knowledge, and not empty vessels into which knowledge can be poured at will" (p. 63).

Almost everyone, including physics students, are familiar with objects that travel in circular paths, such as a merry-go-rounds and perhaps cars on a closed race track. However, the dynamics of circular motion is one of the most challenging topics for physics students (Gardner, 1984).

Panse et al. (1994) states the following:

> In general, the investigations have revealed that students' conceptions have a marked degree of universality that cuts across different cultures, that they have a measure of internal consistency and, what is more important from the point of view of pedagogy, the alternative

conceptions are fairly robust and resistant to [change] formal training. (p. 64)

Students have several misconceptions regarding frames of reference. In this sense, a study conducted by Peters (1982) indicates that these facts hold even true for honor students who exhibit similar conceptual difficulties. According to the author, this indicates that there must be a more serious problem among low-level students. There are some topics extensively researched in physics education. For example, McDermott (1984) conducted a research regarding mechanics subject, Ramadas and Driver (1989) conducted a research regarding geometrical optics.

In this research, high school students' notions were investigated regarding the 'frames of reference'.

The study of Panse et al. (1994) revealed that students think was mostly grounded on tangible things physically attached to bodies. For instance, a ship and its frame of reference both suffer friction in water. The general results of this study also showed that students were unsuccessful to conceptualize the theory of special relativity.

Another study revealed a common misconception about centrifugal force have an effect upon every rotating body. The root of this misconception probably comes from 'experience' of centrifugal force and also the effects of wrong teaching (Ramadas et al., 1996).

Peters (1982) states that for better instruction that will lead eventually to a better understanding of physics concepts, these misconceptions must be researched further.

Problem

One of the central concepts in classical mechanics is the understanding of inertial and non-inertial reference frames. Experts that have internalized classical mechanics know the crucial role reference frames play on the explanations of ridged bodies movements. Research have shown that the majority of high school students have considerable difficulty when it comes to concept of frames of reference. i.e. inertial and non-inertial reference frames. These studies utilized these problems to gain better understanding and insight of students' level of understanding of the phenomenon of frames of references.

Purpose

The purpose of this study was to determine high school students' level of understanding of the concepts of frames of references and also the purpose of this work is to determine misconceptions which students' have regarding frames of references.

Research Questions

1) What is high school students understanding of concepts of inertial and non-inertial frames?
2) Are high school students understanding of concepts of inertial and non-inertial frames gender invariant?
3) Do high school students understanding of concepts of inertial and non-inertial frames change with grade level?

Significance

Result of this study showed how students' understanding of the conceptions regarding inertial and non-inertial character of frames of reference and how its related to pseudo-forces. The study yielded important for physics education, because it is the fundamental of the Newtonian Mechanics. According to results, teachers have an idea about the misconceptions that students have regarding the frames of reference. In this manner, they can find different methods to explain the topic or they can use different materials to increase understanding of students.

Limitations

The free response test and the forced option test were used in this study. Participants may not be truthful because of they know they are being tested. Therefore, this can be limitation. These tests should be conduct in same day with same students otherwise lack of available data. The results are not repeatable and typically the study cannot be replicated. Thus, instruction should be given clearly by the researcher.

Definitions

Inertial reference frame: A frame of reference in which a body remains at rest or moves with constant linear velocity unless acted upon by forces

Non-inertial reference frame: A non-inertial reference frame is a frame of reference that is undergoing acceleration with respect to an inertial frame.

Ethical Considerations

Permission was obtained from the national education ministry, school principals, parents and students volunteered and were given the option to opt out at any time.

CHAPTER 2: REVIEW OF RELATED LITERATURE

Introduction

The purpose of the literature review was to provide sufficient background information regarding the conceptual understanding of physics students studying ‘frames of reference’.

Newtonian Understanding

Newton thought of the concepts of absolute space and absolute time as a kind of axiomatic principle when explaining the motion of objects. Absolute space is the reference system that is assumed to be on average at rest according to the mass distribution in the universe (Mutuş, 1979). "Absolute space is always considered immobile and identical to itself, regardless of anything, that is, according to Newton, absolute space exists separately from objects." (Ward, 2002).

According to Newton, time flows independently from everything that happens in the universe. In other words, 'time' continues to flow at the same calmness and rate even while the movements of the objects continue to accelerate, delay, stop or are suspended (Norton, 2004). In other words, the flow of time does not depend on the speed or other properties of the reference systems. According to Newton, this time is absolute time (Mutuş, 1979).

Earman (1989) refers to Newton's account of time, not to the ontology of time, but to the structure of time. Earman argues that qualities such as space, time, and motion are accepted as terms used to describe the relationships between sensible object, and he divides them into two: first, the relative, explicit and their general acceptance of these relations; second, absolute, real and their mathematical quantities

(Earman, 1989). The explanation of these can be listed according to Newton's system as follows (Newton, 1998):

> Absolute, real, and mathematical time flows by nature, without any relation to anything external. It is independent of time measurements such as hour, day, month, year. Absolute, real, and mathematical space remain the same, without the need of a relation to anything external, and so it is basically stationary. (p.93)

The space (position) of an object is where that object occupies its space. This space can be either described absolute or relative; which in turn depends on whether space is absolute or relative!

Then motion, or better absolute motion is the transition of an object from one absolute place to another. Whereas the relative motion of an object is the transition of it from one relative place to another.

Newton proposed the assumption to distinguish between absolute and relative motions was only possible by accepting the existence of absolute space. The consequence then emergence that inertial forces were determined by a rotational motion (or accelerated translational motion) with respect to absolute space, so that the distinction between absolute and relative motion can be made.

> The effects that distinguish absolute motion from relative motion are the forces diverging from the axis of a circular motion. For such forces do not exist in a simple relative rotational motion, but in a real and absolute circular motion these forces are large or small in proportion to the amount of motion. (p.43)

For example, if we take the rotational motion of a conical pendulum as an example of the above statement, while the conical pendulum rotates, and lets have two different observers watch this this motion. One of these observers observes the conical pendulum without participating in its rotational motion. The other rotates with the conical pendulum. The first of these two observers cannot notice the inertial force that should arise due to the rotational motion in Newton's opinion. The other observer notices this inertial force. According to Newton's claim, the place of the observer in this example is important. In this case, according to Newton, if we define the rotational motion in terms of absolute space, the aforementioned inertial forces will arise. At the same time, the emergence of inertial forces depends on the existence of absolute space (Mutuş, 1979). This contradictory situation has not gone unnoticed by those who do not admit the existence of 'absolute space'.

Bucket Argument

Newton explained his above-mentioned claims with the rotating bucket argument. The experiment is as follows:

A bucket is filled with water. The bucket is placed on a platform. The platform begins to rotate. Thus, with the rotation of the platform around its axis, the bucket starts to rotate. In Mutuş's (1979) words:

> When the bucket starts to rotate, the surface of the water is planar. The relative velocity of the initially maximum water relative to the bucket gradually decreases as the water starts to rotate as a result of the drag of the bucket, and decreases to zero when the water is completely dragged by the bucket. During this time, the surface of the water gradually turns into a parabola. Newton argued that the centrifugal forces that pitted the water surface did not occur during the relative velocity of water relative to the bucket, but as a result of the relative motion of water relative to

> absolute space, suggesting that this experiment involved a rotation with respect to absolute space. (p.62)

A general criticism can be made to Newton's interpretation for the result of this experiment: If the centrifugal forces were caused by relative velocity, these forces should have arisen at the beginning of the experiment, that is, when the relative velocity is maximum. However, according to Newton's explanation, these forces arise when the relative velocity is zero (Maudlin, 1993).

In fact, this movement appears to be easy to describe. However, some difficulties arise when trying to define the movement. Thus, answering the question of how the motion is described is the biggest problem for this experiment (Malament, 1985). The fact that the water surface is initially flat and immediately concave indicates that the water is turning.

Let us say that the rotation of the body of water in this experiment is relative to the bucket. In this case, the water is immobile relative to the bucket. However, standing water surface should be flat, not concave. Therefore, an observer inside the bucket can notice that the bucket is spinning. Then, what is the bucket rotating according to? Suppose the bucket is fixed and the room is rotating. From a relative point of view, a person in the room will see the room as fixed and the bucket rotating. However, the shape of the water surface inside the bucket will not be concave. This indicates that the bucket is stable. As a result, according to Newton, the bucket rotates according to absolute space, not to itself or to the room (Newton, 1998).

In this case, according to Newton, the absolute (real) motion of an object cannot be expressed as relative to other object, that is, the motion is 'relative' (Ward, 2002). The justification for the existence of real motion requires the acceptance of the existence of an' absolute space' (Norton, 2004). In this case, the 'absolute space' presence is needed. Newton explains the existence of "absolute space" with the presence of inertial forces. He explains the existence of inertial forces with the concept of "absolute space". It is clear that these two explanations are a vicious circle (Mutuş, 1979).

Newton's bucket experiment is accepted as a strong argument that space is absolute. This argument discussed above is that space is presented under a substantialist view.

The most intense criticism of substantialists was made by the relationists. One of the pioneers of Relationism, whose views will be briefly explained below, is Leibniz. Leibniz sharply criticized Newton's claim that the rotating bucket experiment demonstrated the existence of absolute space. In the study known as Leibniz-Clarke (Samuel Clarke), Newton's concepts of 'absolute space' and 'absolute time' were tried to be refuted (Earman & Norton, 1987).

Relationism

Newton's views on the ontology of space and time, briefly explained above, are known as "substantivalism " (Sklar, 1977). The other view that does not accept this view is called "relationism " (Norton, 2004). Relationism is the view that suggests that space and time can be explained by the relationships between objects and events. The views of the relationists on space and time against substantivalism will be briefly discussed below.

Relationists claimed that empty space is a conceptual impossibility. Such a space is an abstraction that relationists use to compare the motion of bodies. That is, according to the relationists, space consists of spatial relations between substances. Relationists hold the view that assuming that all matter has disappeared, there cannot be anything that can be called space, since there is no matter to be referred to. In other words, relationists evaluate the movements of objects according to each other or something else. Although the relationists did not accept the reality of space, they did not completely reject the absolute (true) motion of an object since they claimed that absolute (true) motion can be determined by relative motion and its effects (Norton, 2004).

Time, according to the relationists, is a measure of the succession of changes in the universe. Therefore, this means that if there is no change anywhere, there is no timeline. For them, time is a temporal relationship between events (Norton, 2004).

Berkeley strongly opposed Newton's idea of absolute motion. In the words of Berkeley (1999):

> If everything is relative, all movements are relative too. Movement cannot be understood without determining its direction. The direction of the movement cannot be understood except in relation to us or any object. Directions such as up, down, right, left are based on a number of relations. It is necessary to assume a different object other than the moving object. Movement is therefore relative in nature. In other words, motion cannot be understood unless the relations of objects with other objects are given. If there are no objects in relationship with each other, there can be no relationship at all. Based on this view, it is possible to say the following: If only one object remained in the universe, it would be impossible and meaningless to describe the motion of this object. (p. 110)

Let's consider two objects now. Suppose there is no substance other than these. In this case, a circular motion of these two objects within the frame of their common center cannot be imagined. But if a cluster of stars were suddenly created, it would be possible to imagine the movements of these two objects according to different parts of the celestial sphere, because of their relative positions. (Berkeley, 1999, p. 113).

As can be seen from this example, Berkeley actually substitutes a "set of fixed stars" for Newton's "absolute space" concept. According to Berkeley, the motion of an object can only have meaning because of its relative motion relative to other objects.

Mach reinforced Berkeley's thoughts. According to Mach, there are no distinguishable parts of absolute space and absolute time by definition. That is why Mach said that according to these, there could be no method to bring about a change (Mashhoon, 2016). For this reason, he argued that talking about absolute space and absolute motion would be meaningless (Mutuş, 1979).

Mach stated that the concept of "absolute space" that Newton assumed to explain the events of inertial was an unnecessary hypothesis. Mach argued that these events can also be explained through a scheme based on the concept of relative motion (Mutuş, 1979). Mach continues his views as follows:

> I think there are relative motions… If an object rotates according to fixed stars, centrifugal forces arise. If it rotates with respect to another body and not with respect to fixed stars, no centrifugal force occurs ... Newton's experiment with a bucket of water shows us that water only reveals a significant centrifugal force relative to the walls of the bucket, but the relative movements of such forces with respect to the masses of water, the earth and other celestial bodies hence it shows that they emerged. No one is authorized to say what kind of experiment would be

if the thickness and mass of the walls of the bucket increased

'extremely. (p.78)

According to Mach, the kinematic description of motion also takes on a dynamic meaning. In fact, according to Mach, space does not have a meaning on its own (Ehlers, 1973). Mach expresses space as an abstraction of the distance relations between objects. According to him, local inertial systems are determined by an average of the movements of masses in the universe. The masses have only relative motion relative to each other. Kinematically equivalent motion is also dynamically equivalent. These views of Mach are called the "Mach principle". According to this principle, matter has inertia not with respect to space, but with respect to matter (Mutuş, 1979).

Inertial Reference Systems

Einstein published his special theory of relativity in 1905. Special relativity is concerned with problems involving inertial reference systems (Beiser, 1997). Einstein built this theory on the assumptions that the speed of light in inertial reference systems is constant in space and that the laws of physics are formally preserved by Lorentz transformations. The Special Theory of Relativity has two basic postulates as the Relativity principle and the light postulate.

The description of the position of any object in space or the state of an event is based on the determination of the point on a solid where that object or event coincides (Einstein, 2012). In physics, this determination is made through geometric systems. These geometric systems are called 'reference systems'. Saying that an object is moving always predicts the existence of a certain reference system (Beiser, 1997).

In classical mechanics, reference systems that make steady linear motion according to the steady system are called "inertial reference systems". If there is no force acting on the object in such a system:

1) If the object stops, it continues to be at rest,
2) If the object is in motion, it continues its motion with constant velocity (both magnitude and direction).

Movement with these characteristics is called 'steady motion' (Beiser, 1997).

Every reference system moving with a constant speed relative to an inertial reference system is also an inertial system (Einstein, 1920).

With his special theory of relativity, Einstein informs us that there is no universal reference system or "absolute motion" that can be used everywhere (Beiser, 1997).

According to Principle of Relativity put forward by Einstein, the laws of physics are the same under Lorentz transformations in all inertial reference systems (Einstein, 1920). An observer standing still with respect to a reference point and another observer moving uniformly with respect to that reference point perceive all the laws of motion as the same (Friedman, 2014). In other words, all systems of inertia are equivalent to each other in the expression of the laws of physics. The laws of physics tell us what physical processes can or cannot be. As it was known before Einstein, it was possible to talk about "absolute motion" based on the concepts of "absolute space and absolute time". However, the principles of Einstein's Special Theory of Relativity do not regard space and time as absolute, as will be pointed out below (Norton, 2013). These principles are examined in outline below:

Newton's design of the universe required the existence of an absolute space. Absolute space meant a universal reference system. Einstein's Postulate on Relativity is based on the understanding that such a universal reference system cannot exist (Beiser, 1997).

The important consequences of this principle can be listed as follows: Absolute speed concept does not exist in any natural law. No experiment can demonstrate absolute motion (Norton, 2013).

Hence, there is no universal reference system or "absolute movement" that can be used everywhere at any time (Beiser, 1997).

However, the Special Relativity principle is limited to systems of inertia. Therefore, this principle does not cannot cover accelerated movements.

According to second postulate of special relativity principle put forward by Einstein, the speed of light is the same for all inertial reference systems. The speed of light is indicated by the symbol "c". Light travels approximately 300,000 km per second in space. The speed of light does not depend on the speed of the observer in the inertial system. In other words, the observer determines that the speed of light is invariant (the measured value is the same) in all inertial reference systems, regardless of the inertial reference system (Einstein, 1920).

One of the most important reasons why Einstein revealed his light postulate is his work on electrodynamics, electric and magnetic field theories. These theories were the most advanced physics theories of that time. Maxwell revealed that light is a kind of electromagnetic wave. Maxwell's equations assume that the speed of light is an unchanging "c" hence a constant (Rindler, 1994).

As a consequence, the speed of light in vacuum is the same for observers in all inertial reference systems. According to these observers, the speed of the light in space does not depend on the speed of the source that produces the light. In other words, factors such as how light is produced and the speed of the light source do not affect the speed of light in space. Whatever the speed of light in space (vacuum) is always the same, it doesn't change (Einstein, 1920).

According to Einstein, the fact that the propagation velocity of light in space is the same to all inertial reference systems meant the end of the concept of absolute time proposed in Newtonian mechanics. Before Einstein, there was always a discrepancy between Newton's mechanical principles based on the laws of motion and the principles of electricity and magnetism developed by Maxwell as a unified theory. Newtonian mechanics has solved many problems for more than two centuries. Newtonian mechanics are invariant under Galilean transformations in inertial reference systems. But Maxwell's equations do not remain invariant under Galilean transformations (Beiser, 1997).

Mathematical Transformations

In the special relativity theory, mathematical transformations were found between the space-time coordinates of observers moving freely with respect to each other. The physical meaning of these relations, which are named after the Dutch physicist Lorentz and called Lorentz transformations, consists of showing how events are perceived by freely moving observers. Maxwell's equations remain formally invariant in systems of inertia under Lorentz transformations. It has been shown by Einstein that these transformations are the invariance of light between inertial reference systems and transformations that can be deduced based on the Special relativity principle (Einstein, 2012).

Lorentz transformations are real transformations between inertial reference systems based on observations. Galilean transformations are based on assumptions. Einstein showed with special relativity that Maxwell's theory is consistent, but Newtonian mechanics is not. Relativity mechanics and Newtonian mechanics give the same results for velocities smaller than the speed of light. That is why Newtonian mechanics has been valid for so long. At higher speeds, Newtonian mechanics is not valid. At these speeds, Einstein's theory of relativity is valid (Beiser, 1997).

The general theory of relativity is the relativistic theory of gravitational forces. In other words, instead of Newton's universal law of gravitation, which gives the interactions between objects in a stationary and eternal universe, it is the case that all celestial bodies are in a changing and expanding, non-absolute space. It is known as the law of gravitation, which is valid in a universe where they move with respect to each other.

General relativity theory is based on four basic principles: These are 'equivalence principle', 'Geodesic principle', 'Mach's Principle' and 'General covariance principle'. Let's briefly consider these principles:

According to equivalence principle, "the inertial mass that determines the acceleration of an object when a force acts is equal to the gravitational mass that determines the magnitude of the gravitational force exerted by another object." (Akdaş, 2012). According to Einstein, this interpretation is obtained by accepting the statement that the same quality of an object manifests itself as Inertia or Weight depending on the situation.

This principle, expressed as equivalence, is that gravitation forces and inertial forces are indistinguishable in the case of a very small local space region, and this is based on the equivalence of inertial mass and gravitation mass. According to this principle, there is an equivalence between inertial fields and gravitational fields. The free fall motion of all objects in the gravitational field is the same. Therefore, the free fall motion does not depend on the type of objects. Therefore, the free fall of objects, that is, the properties of the gravitation field, are linked to the law of space-time

(Akdaş, 2012). The equivalence principle can be understood more clearly with the "geodesic principle".

According to Geodesic Principle of Einstein, when all objects are not subjected to any force other than gravity, they act on geodesics. This is the expression of the principle of inertia in Riematic spaces (Akdaş, 2012).

This principle is known as the geodesic principle or the geodesic law of motion. "Geodesics are the" shortest curves "on such a surface, when considered as an example that connects two points on a two-dimensional curved surface." (Penrose, 2001). This concept is a geometric expression of the trajectory followed between two points. For example, geodesics on a sphere surface are all the major circles of the sphere (Rindler, 1994).

In special relativity, geodesics are linear lines. According to Einstein, the paths of free-falling objects in the gravitational field are the geodesics of the space-time metric. This metric is a curve metric. In a sense, the geodesics of curved metric can be thought of as curves that are "closest to the straight " (Brown, 2005). Einstein gave the skew of the trajectory of light rays under gravity as an example.

Mach's principle is the principle that defines the inertia of a body as a function of all bodies in the universe. This principle states that the geometric structure of space-time can be determined by the material that reveals the gravitational field (Sklar, 1977).

Mach thought that the distribution of matter in the universe could affect locally defined concepts in physics. Einstein stated that the theory, which states that the law of space-time is not always constant, but can change with the effect of matter in the universe, can also describe gravitation (Sklar, 1977).

Newton's absolute space is not affected by mass. However, according to Mach, this is not the case. Mach's principle argues that local inertial effects are the result of the interaction of the system under study with the entire mass in the universe. In mechanics, Mach tried to dispel the assumption that space is an effective cause.

According to Einstein, the masses in the far corners of the universe and their motion according to the system we are working on are "the causes of the different behaviors of the system and can be tested by observation". Einstein's theory of General Relativity, following Mach, argues that where there is no gravity, space must also disappear: Where there is no gravitational potential, neither space nor a piece of space can exist; because gravitational potential determines the metric properties of space and without these properties it is not possible to design space (Pekünlü, 2005).

According to the general covariance principle, the laws of physics should be expressed in a manner that preserves the same shape in all reference systems that can be passed from one to another (Jacobin) with non-zero, continuous and derivable coordinate transformations. In other words, this principle is to express the field equations of the relativist theory of gravitation independently of the coordinate systems.

Einstein interprets the results of the General Relativity Theory as follows:

> According to the theory of general relativity, the law of the constancy of the speed of light in space, which is one of the two basic assumptions in the special relativity theory, cannot claim an unlimited reality, and the curvilinear motion of light rays can only occur when the propagation speed of light changes with the ground. (Akdaş, 2012)

This curvature is a scale of gravitation. Einstein stated that the space-time continuum under the general principle of relativity is not an Euclidean continuous. The principle of general relativity allows us to calculate the influence of the gravitational field on all processes occurring according to known laws when there is no gravitational field (Akdaş, 2012).

> According to the general theory of relativity, the geometric properties of space are not independent and are determined by matter. The universe cannot be Euclidean if we want an average density of matter that is non-zero no matter how small the difference is in the universe. On the contrary, the results of the calculations indicate that for matter to disperse properly, the universe must be spherical (or elliptical). In reality, since the distribution of matter is not uniform, the real universe will move away from the spherical structure, that is, the universe will be spherical, but it is absolutely finite. Indeed, the theory gives us a simple relationship between the average density of matter in the prevalence of the universe in space. (p.48)

General relativity is a geometric theory; because this theory gives a dynamic role to the space-time metric. The curvature created by the mentioned geometry shows itself as gravitational fields in the universe. General relativity equations express what the space-time geometry is like. By solving these equations, the space-time geometry and gravitation fields around all objects are found. According to this theory; space-time curvature replaces the concept of force. The environment of matter changes the curvature of space-time (Bozdemir & Çavuş, 1998).

In classical mechanics, time is regarded as constant and universal, independent of the observer's state of motion. According to the relativity principle, time cannot be thought apart from the three dimensions of space. The passage of time, considered as the 4th dimension, is related to the speed of light and gravitational fields. These gravitational fields can slow the passage of time. This situation also depends on the movement of the observer.

According to Einstein, the universe is a finite, curvilinear and four-dimensional structure (Minkowski, 1908). The space we live in is not an Euclidean space, but a 3-dimensional affine space. The fourth dimension for him is time. According to Einstein, time is relative. Time is defined according to the reference system to which the observer is connected. Newton's system is based on the definition of motion. In this system, it is possible to associate the motion of an object with absolute time. The acceptance of the concept of time in the Newtonian system is inevitable in terms of the "universe model" and assumptions it envisages.

According to Einstein, mass creates curvatures in space-time. In other words, the existence of matter changes the space-time geometry. This curved space-time geometry is called "gravitation". According to the inertial reference system of the observer in the aforementioned curvature, time passes slower than in the inertial reference system of an observer outside the curve. In other words, objects create curvatures in space according to the size of their masses and slow the passage of time. In other words, as the strength of the gravitational field increases, the spacetime curvature also increases.

"According to Einstein, the concepts of space and time are inextricably intertwined. A length that an observer can only measure with a ruler, another observer can only measure with a ruler and a clock” (Beiser, 1997). The merging of space and time is known as the" space-time continuum. " The space-time continuum is a mathematical model. According to the Special Relativity Principle, events are assumed to occur in a four-dimensional spacetime. The three known coordinates 'x, y, z' indicate the position in space, and the fourth coordinate 't' indicates the time. Even if we can't imagine space-time, its mathematical use is no more difficult than that of three-dimensional space (Beiser, 1997).

As you can see, the subject of frames of reference contains very complex and difficult to learn subjects and topics. In this respect, examining the difficulties experienced by physics students in learning physics is a very important issue for literature.

Students Understand of Physics Concepts

In the studies conducted in different countries on students understanding of physics concepts, thoughts, and theories has attracted considerable attention. In the studies, it has been determined that students with different backgrounds and different age groups come to the lessons with different ideas that have a great impact on their learning process (Halloun & Hestenes, 1985; Trowbridge & McDermott, 1980; Viennot, 1979). The knowledge and experience of the students about these concepts are mostly ideas that do not coincide with scientific truths presented in the courses.

These thoughts that students have, were named as "misconceptions" or, more commonly, "alternative concepts" (Marton, 1986; McDermott, 1991). Alternative concepts have been developed by the students themselves as a result of their desire and experience to understand nature. The following 6 different situations related to students' alternative concepts have been accepted (Millar, 1989). These are;

1) Students come to the lesson with the usual thoughts they encounter in their daily life.
2) It is very difficult to replace these alternative concepts with traditional teaching methods.

3) These alternative concepts are parallel to previous scientists' way of explaining nature.
4) The alternative concepts each student has are based on their personal experiences, cultures, feelings, language and education they receive in schools.
5) Some teachers have the same alternative concepts as their students.
6) Alternative concepts students have contradicting ideas with the knowledge provided in formal physics education.

Over the last decade, investigation of students' domain-specific notions has been an active area of physics educational research. For instance, McDermott (1984) did a scientific study regarding mechanics, Ramadas and Driver (as cited in Panse, 1994, p. 63) conduct a research regarding geometrical optics (Ramadas & Driver, 1989, as cited in Panse et al., 1994 p. 63).

Generally students have conceptual difficulties with physics. Peters (1981) conduct a study with honors students between the years 1978 to 1980. The author used written questions on exercises and exams to determine conceptual difficulties. The results show that honor students have many of the same kinds of conceptual difficulties which lower-low students have (Peters, 1981).

Quantization, electron diffraction, photoelectric effect, light and atom models have been studied in most of the researches on modern physics (Aubrecht, 2003; Thacker, 2003). Aubrecht (2003) determined students' thoughts on the concept of photon in a study with students who did not take the quantum mechanics course. Thacker (2003), on the other hand, investigated the thoughts of the students about photoelectric effect, diffraction experiment and determination of e / m with his study. In this study, the structure of the pre-concepts in modern physics subjects and the physical models developed in their minds before and during education were determined with the help of questions asked about macroscopic representations. According to the results of this research, in order for students to understand the concepts of modern physics correctly, they must realize that the observations or samples of daily life provide the development of models related to microscopic processes.

Johnson et al. (1998) in their study with the University of Sydney undergraduate students entitled “The difficulties students face in learning quantum mechanics”, they tried to find answers to three research questions. (1) What is a particle? (2) What is a wave? (3) What is uncertainty? In this study, three different types of analysis were made: content, category and true / false. For the first research question, three different categories were identified: (1) a particle is a substance, (2) a particle is a substance that moves along a certain orbit, (3) a particle is a substance that moves along a certain trajectory and is sensitive to external forces. By analyzing the students' answers to the second question, two different approaches were determined. While 17 students explained the wave as a localized concept based on the definitions in the quantum mechanics books, 31 students talked about the wave properties. Seventeen out of 32 students were able to fully explain the relationship between the wave concept and other physical concepts and associate some properties (such as interference, diffraction) with particles and waves. While "momentum concept" is a frequently used concept for particle, "Fourier analysis" for wave has been determined as a frequently used concept. The concept of uncertainty has not been analyzed due to the diversity in student responses. Another study on modern physics topics was conducted by Euler (1999). This research is aimed at changing the conceptual knowledge of prospective teachers in Germany about modern physics and their thoughts on these issues. Atomic models constitute the main subject of the research. Participants were divided into two groups as experimental and control groups, and all of them took the quantum physics course. In addition, all of the students in the experimental group participated in a different courses about the concepts and models in quantum physics as well as the quantum physics course.

According to the pre-test results conducted at the beginning of the study, most of the students applied the models used in classical physics towards quantum concepts. Considering the pre-test results, although there was no statistically significant difference between the experimental and control groups, it was found that there was a conceptual change in favor of the experimental group in the post-test performed at the end of the practice. Şen (2000), in his study on quantum physics lessons, emphasized that it would be important to teach the subjects in high school physics lessons. In this study, important suggestions on quantum physics teaching in Germany were examined and the necessity of these suggestions for Turkey was emphasized. Didiş et al. (2007) investigated the perception of some concepts that allow physics teaching students to explain the quantum mechanics postulates in a qualitative study, and found that prospective teachers had difficulty in explaining, distinguishing, relating and mathematically expressing basic concepts. Mashhadi and Woolnough (1999) investigated how high school students envision the concepts of electron and photon in their minds. As a result, it has been revealed that students have a wide variety of non-scientific representations in their minds.

Another study was conducted by the physics education research group at Washington University on learning difficulties for diffraction and interference issues at the modern physics level (Ambrose et al., 1999). In the analysis of the data obtained through the interviews with the students, it was determined that the students had some difficulties regarding the diffraction pattern and how the pattern would be affected by the change of the slit interval (Steinberg et al., 1996). The difficulties experienced by the students in applying the wave model in the light interference event were investigated by other researchers in the same research group (Wosilait et al., 1999). In another study conducted by Stamatis et al. (2000), it was observed that students could not explain the diffraction and interference phenomena with the wave model. In addition, these students also consider the Broglie wavelength as a particle-specific property rather than a function of momentum.

Learning Difficulties in Modern Physics

Learning difficulties in modern physics topics such as the special relativity principle are studied with great interest by researchers working in the field of physics education. The discussions on the curriculum regarding the content of the introductory courses in the early 21st century mostly reflect the intellectual ideas of the 20th century. Physics education research plays a very important role in this field. Although students encounter modern physics concepts in introductory or advanced courses, it is very important to determine in which subjects they are successful and whether they understand the concepts in depth as a result of teaching. In addition, analyzing the relationships between the concepts that students learn and the concepts they make sense of by identifying them with their daily life can be useful for the reasoning required to teach advanced topics (Scherr et al., 2001).

It is striking that there are few studies on the special relativity principle in the literature. Most of the research is about Galileo relativity (Panse et al., 1994; Ramadas et al., 1996). The data collection tools (multiple choice questions or open-ended questions) used in most of these studies are not capable of revealing students' views and reasoning skills and helping to develop effective teaching strategies.

Therefore, in the studies conducted in this part of the thesis, in addition to the problem solving tasks given to students in order to identify open-ended questions and mathematical difficulties, semi-structured student interviews were also conducted with the students selected according to the results obtained as a result of the application.

The main purpose of these interviews with students is to investigate the students' thoughts about the concepts of the special relativity principle in more depth and to increase the reliability of the research conducted with the collected data (Yıldırım & Şimşek, 2006).

According to the studies of Panse et al. (1994) and Ramadas et al. (1996), reference frames are limited physical sizes for many students. In addition, according to the students, an object can leave its environment and go out of the reference frame (such as throwing a ball out of the reference frame it is in). In their study, Saltiel and Malgrange (1980) determined the difficulties of 11-year-old students and first and fourth-year university students about relative movement. In these studies, many of the students defined the motion of an object as an "internal" property rather than a measurable size relative to the frame of reference. In addition, in this study, students divided motion into two as real motion with dynamic effects and visible motion that is not physical, consisting entirely of optical illusions. Villani and Pacca (1987) showed that the reasoning of university students about special relativity was similar to that of Saltiel and Malgrange's work on Galileo relativity.

Ramadas et al. (1996) conduct a study in order to determine students' notions regarding inertial and non-inertial reference frames and pseudo-forces particularly the centrifugal force. 29 physics undergraduates from Bombay College participated. Qualitative analysis of data provided the describing of misconceptions.

One of the misconception is when you with the frame this means that it is inertial; when you looked at from “outside” this means that it is rotating. This frequently express in physics teaching for defining Newton’s first law of dynamics. However, there is no priori kinematic criterion for deciding if a frame is inertial or non-inertial. That is why in some situations students create simple kinematic criteria for the purpose (Ramadas et al., 1996).

Ramadas et al. (1996) indicate in their study a common misconception among students. According to the results of analysis, students think that centrifugal force acts on rotating objects. This shows that revolving stone or child in a merry-go-round are acted upon by centrifugal force irrespective of the frame of reference.

This study also revealed that “experience” in life also led to occurring misconceptions. For instance, if you are on a merry-go-round you feel being pushed out because of there is a centrifugal force on the child but not on the man which standing by merry-go-round.

Panse et al. (1994) conducted another study in Bombay College. The free response test involves a number of different situations regarding the notion of frames of reference. 50 physics undergraduates were participated in this phase of study. The forced-option test constitutes the second part of the study. The test contained a variety of diagnostic problem situations.

The study revealed that students sometimes uses of word ‘fix’ or ‘not movable’ while they were talking about frames of reference. This means that they admit frames as if they were tangible objects (Panse et al., 1994).

Panse et al. (1994) states the following:

> The overall impression that results from our analysis is that physics undergraduates tend to take ‘frame of reference’ as a decorative ploy

> with no explanatory purpose, and generally fail to show a metaconceptual understanding of ‘frames of reference’ as a tool for the proper formulation and exploitation of the physical principle of relativity. (p. 75)

Ramadas et al. (1996) conduct a study regarding transformation of time, distance, velocity and energy between frames of reference. This study also investigated is students’ mete-conceptual understanding of the word ‘laws’ and the phrase ‘invariance of laws’. This study is also conduct in Bombay College with 39 physics undergraduates.

Ramadas et al. (1996) states the following into their study:

> The invariance of distance interval between simultaneous events for example length of an object is a consequence of Galilean transformations. Many students, however, take invariance of distance for granted regardless of whether the events are simultaneous or not. Strong adherence to this conception can lead to violation of time invariance. (p. 465)

There is a common misconception among students that energy is constant from one frame to another. Students have this misconception because conservation of energy is taught to the students as if something should not be queried. This shows that the meta-conceptual understanding of 'laws' is inadequate.

In a case study conducted by Hewson (1982), it was found that physics graduate students had “metaphysical” thoughts about special relativity. In this study, students define relative effects (such as length shortening, time dilation) as “perception distortions”. Similar results were obtained in another study conducted by Posner et al. (1982) by interviewing students and academic staff.

The concept of reference frame has a very important place in relative movements. For this reason, the lessons in which the special relativity principle is explained begin with the explanation of the reference frames in which the position and time measurements of the observers related to an event are made. Understanding the reference frames on the basis of every subject in the principle of special relativity has a very important place in the teaching of the subject. Determining the kinematic magnitudes of the systems and getting an idea about the measurements made by different observers can be explained by using reference frames that move relative to each other. Operational definitions of reference frames should be made first in order to make discussions such as determining the location of an event, measuring time, and under which conditions the synchronization of events will be possible.

Accordingly, the mentioned operational definitions can be given as follows. Event: In the special relativity principle, an event is a state associated with a single location in space and a single "moment" in time.

Location of an event: It is the definition of the coordinate values related to the state of an event on a rigid ruler. The rigid ruler mentioned here is considered to be a size extending infinitely from some chosen starting point.

Time of an event: The time value of a clock located at the place where an event occurred, indicated at the time of the event. The clock and rulers used by each observer are in a static state relative to the observer.

In the special relativity principle, observers who measure in all reference frames use synchronized clocks. To determine the times of events occurring at different points, observers measure the travel time of the signal related to the event. Observers who are stationary with respect to each other determine the same location and time values for an event that occurs. It can be concluded that these observers who make such measurements are in the same reference frame.

According to the time definition in the special relativity principle, they are defined as "simultaneous" with the event corresponding to the same time values with each other in a given reference frame. The result of the synchronicity of events occurring at a certain distance from each other requires proper definition of the times related to these events. This result is an indication that the speed of light remains constant in all reference frames. Events occurring simultaneously at different points of a reference frame may not be synchronous in all other reference frames where there is relative motion.

CHAPTER 3: METHODS

Introduction

This chapter presents the methodology of the study, explaining the population and sampling, the data collection instruments, and the statistical techniques used in analyzing the data.

Research Design

This study used a descriptive quantitative research methodology to investigate high school students' levels of misconception on inertial and non-inertial reference frame. To this end, a test consisting of two parts was used. The first part of the test contained seven open-ended questions, and the second part consisted of multiple choice questions.

At its most basic, describe research is at attempt to understand natural or man-made phenomena. This type of research limits itself, that is, it is not directly concerned with causes or causal relations. It is an attempt to reveal the forms of and changes in phenomena, as well as their similarities and differences with other phenomena. Despite of this basic form of research, scientists have made important discoveries through description of phenomena. Therefore, descriptive research also occupies an important place in educational research (Gall & Borg, 2006).

Scientific research is a dynamic process that aims to examine phenomena, obtain information through observations, and thus solve problems. The functions of the research are to define, explain, understand, supervise, see and direct the events (Balso & Lewis, 2007).

In short, non-scientific research is a way of acquiring non-scientific knowledge based on certain subjects and traditions. It is a form of obtaining information that is not based on empirical research, does not have a verification process and does not ask questions (Balso & Lewis, 2007).

Descriptive research methods, which are also used in theory formation studies, aim to define the processes that occur in a social environment. The process is tried to be defined comprehensively by comparing each finding obtained with other findings in the literature (Scherpenzeel & Saris, 1997).

Sampling

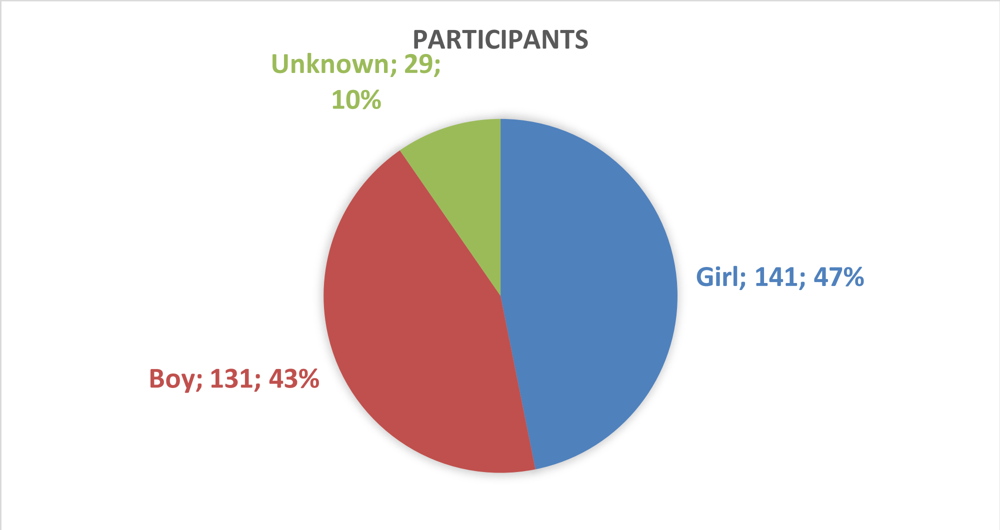
The study was conducted in five public schools located in Çankaya district of Ankara in 2018-2019 education season. Four of were Anatolian high schools, and one was a Science high school. The test was administered to a total of 361 students, who were 9th, 10th, or 11th graders and volunteered to participate in the study. Students were given 20 minutes to complete the questionnaire. Figure 1 shows the numbers of students who participated from each school.

Participants

The study was conducted in five public schools located in Çankaya district of Ankara. Four of the five schools were Anatolian high schools, and one was a Science high school. Of the 361 questionnaires completed, 60 were excluded from statistical analysis because they contained missing data.

Figure 1

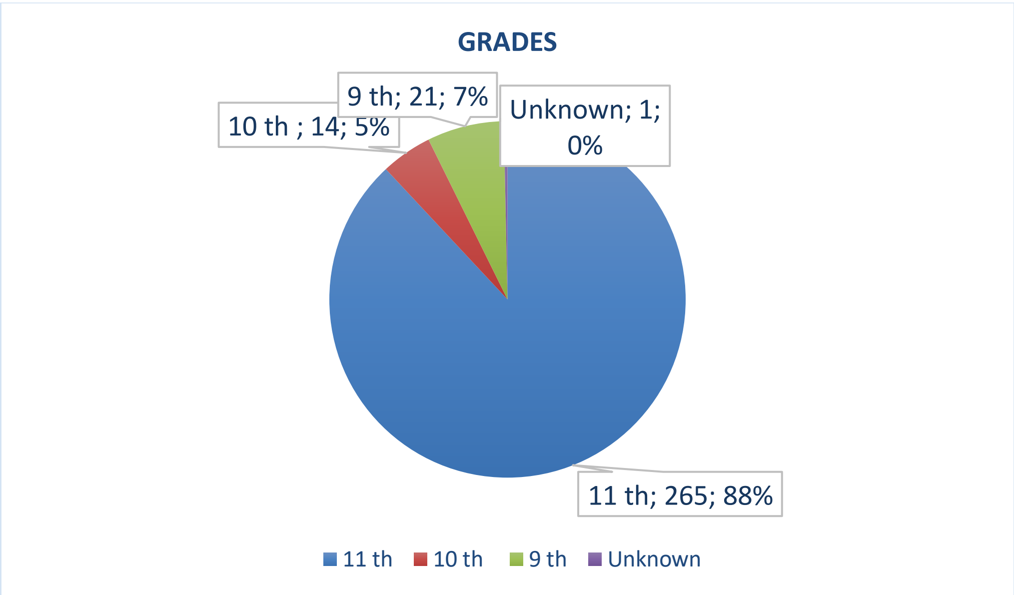
Number of Participants Who Participate in Research



As Figure 2 shows, male students made up 43% of the participants, and female students made up 47%. 10% of the students opted out to report their gender.

Figure 2

Level Distribution of Students Participating in the Research



As Figure 2 shows, a large majority of the participants, 88%, were11th graders. The proportions of 9th graders and 10th graders among all participants were very close to one another, with the former making up 7% and the latter 5% of participants.

Instrumentation

Quantitative data for the study were collected using the survey test developed by Ramadas, Barve and Kumar (1996). The questionnaire consisted of two parts. The first part contained seven open-ended questions. (Appendix A). The content of the questions is about inertial reference frames. The second part consisted of multiple-choice test. (Appendix A). In this part of the questionnaire is about rotating frames.

Validity is the degree to which a tool can accurately measure the property it aims to measure without confusing any other feature (Tekin, 1977).

Reliability, which is one of the features that the scale should have, is an indicator of the stability of measurement values obtained in repeated measurements under the same conditions with a measurement tool (Carey, 1988). Confidence should be made that the information provided with the scale is stable, that is, it is error-free and that the same results will be obtained in a second measurement for the same purpose (Carmines & Zeller, 1982). An unreliable scale is useless (Gay, 1985). The analysis of the data was made with the SPSS 21 program and it was worked with a 95% confidence level. The kurtosis and skewness values obtained from the intra-item scales are between +3 and -3 are considered sufficient for normal distribution (De Carlo, 1997; Groeneveld & Meeden 1984; Hopkins & Weeks, 1990; Moors 1986).

Items on the questionnaire were open-ended and multiple-choice questions designed to observe students' misconceptions of inertial and non-inertial frames of reference, pseudo-forces, and centrifugal force.

Translation Procedure

The original survey was in English, a panel was created to ensure a faithful and equivalent translation. According to Vinay and Darbelnet (1995), equivalence-oriented translation is a procedure that "replicates the same situation as in the original, while using completely different wording." (p.454, 2016).

The test was first translated to Turkish by the researcher. Then, the translation was evaluated by two prospective physics teachers and two prospective English teachers in terms of their respective fields of expertise. The researcher and the evaluators then came together and discussed the differences between the original and the translated versions of the questionnaire, following which the Turkish test was finalized.

Method of Data Collection

To administer the questionnaire to the students, first, the required permissions were obtained from the Ministry of National Education. After obtaining the permissions, the questionnaire was administered in the Spring semester of the Academic Year 2018-2019 in volunteering schools. The questionnaire was administered by the researcher personally.

Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPPS) 20.0. To make an in-depth analysis of students' misconceptions, each question was evaluated separately using CTT. The first part of the questionnaire consisted of seven open-ended questions. Categories were created on the basis of students' responses to each question. Responses were assigned a value of 1 if they contained a particular category and a value of 0 otherwise, data entry was carried out for each question, and then data were analyzed using OLAP (Online Analytical Processing) by gender and grade.

CHAPTER 4

Introduction

This chapter provided detailed information on the statistical results of the study conducted. The test, that was applied to high school students, consisted of two parts, A and B. Part A of the test was composed of seven open-ended questions. Part B had twelve forced multiple-choice type questions. First, the statistical results for part A were reported. Since the data of the first part were obtained through open-ended question which needed the initial procedure of creating categories, a straight forward descriptive item analyses was not possible. Descriptive item analysis is a common procedure employed mostly for tests composed of multiple-choice type questions. Instead, after creating common categories, part A of the test was analyzed through a process known as Online Analytical Processing (OLAP) Cube by utilizing SPSS.

OLAP Cubes Procedure

The OLAP Cube procedure is used whenever researchers are interested in summary statistics for scale variables – as those obtained from part A. The primary purpose of descriptive statistic is to provide interested parties with analytical results of complex data in a more condensed form to form an overall opinion about the phenomenon at hand. When categorical variables exist, the OLAP Cube helps to break down and analyses the data by utilizing the categories of those many grouping variables (see Table 1 for grouping variables). As a result, after running an OLAP Cubes procedure, the researcher can obtain many statistics. It is possible to calculate the following measures: “counts, sums, central tendency and variances”.

The researcher is not restricted with the number of grouping variables, any number of grouping variables are allowed to be used and supported by SPSS. In this research the specific numbers of categories weren't known in advance. The exact number could only be determined after collecting the data and then creating the categories. One more important feature that is possible is referred as "pivot". The pivot process of variables allows to create layers by utilizing the column or row to simultaneously display its categories that is being studied. This feature allows the user to work on a 2D data table but operate at a higher-level dimension, hence the term Cube (3D). Otherwise, one would have had to create a separate spreadsheet for each category. This process, that is the creation of separating data sheets is a time-consuming process prone to many mistakes.

Process of Category Creation

Before conducting the OLAP Cube analyses, categories i.e., scale variables needed to be determined. The categories for each question were created from the answers given by the students on part A of the test. As mentioned above, the students were required to write an answer to the seven open-ended questions. Boolean (0, 1) data were used to mark the presence of the category. The researcher awarded the student answer with a point if the student answer included relevant information pertaining to the concepts being probed. As the study tried to unveil students' understanding of the concept of inertial and non-inertial reference frames, all answers that had some sort of information regarding the topic were scored based on the category the answer fit. Thus, the information provided needed to create the categories was not limited to only correct answers. Central themes that eventually formed the categories were recorded as they emerged from the student answers (see Table 1).

If a student answer did not pertain to the topic or there was no answer, it was scored zero. This was the scoring procedure of students' answers about inertial and non-inertial reference frames. Table 1 showed the resulting categories. As can be seen in Table 1, question 1 had 6, question 2 had 5, question 3 had 8, question 4 had 5, question 5 had 9, question 6 had 3, and question 7 had a total of 4 categories respectively. The total number of categories were found to be 40.

Table 1

List of Categories for Each 7 Questions of Part A

Question Number	Themes	
1	1	Direction
	2	Inertia
	3	Centrifugal force
	4	Force
	5	Other
	6	No answer
2	1	Backward
	2	Inertia
	3	Forward
	4	Bus seat
	5	No answer
3	1	We are on the earth
	2	Rotation
	3	Size
	4	Copernicus thesis
	5	Absolute reference
	6	Gravitational force between the sun and the earth
	7	Related to mass and dimension
	8	No answer
4	1	There was a CF on the child
	2	Centrifugal force on the man
	3	No CF on man
	4	There was no CF on the child
	5	No answer
5	1	Forward inside the train
	2	Forward (ground observer)
	3	Backwards (inside the train)
	4	Backwards (ground observer)
	5	Steady (inside the train)
	6	Steady ground observer
	7	Inertia
	8	Relative motion
	9	No answer
6	1	True
	2	False
	3	No answer
7	1	Relativity
	2	Because of gravity
	3	Different environment
	4	No answer

The sequence or algorithm of sorting the categories listed in Table 1 for each question is based on the frequency responses. That is, category 1 for each question is the highest “scored” or “marked”, then followed by the next highest one. “No answer” was always kept as the last category, despite its frequency or score.

Answers and Results for Question Number 1 Part A

The first question was "Imagine yourself sitting steady on a rotating merry-go-round. In which direction do you feel yourself being pushed? Why? Then what prevents our motion in that direction?" Six categories were determined after scoring all student answers. These were inertia, centrifugal force, force, direction, other and no answer. No answer is fairly self-explanatory. The answers that included participants’ sense of direction were scored under the category “direction”. Students that provided written answers but did not fit any particular category were different and did not fit into any category were labeled as “other”.

For question 1, Tables 2 to 7 provides descriptive statistical information for each of the 6 categories determined and listed in table 1 respectively.

Category: Direction

Table 2 shows the descriptive statistics results on the third category labeled as direction by gender and grade level.

Table 2

Descriptive Statistics for Students who Stated Direction by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	12	15	4.7%	5.0%
		10th	4	7	1.6%	2.3%
Direction	M	11th	89	108	34.5%	35.9%
		x	1	1	0.4%	0.3%
		Total	106	131	41.1%	43.5%

Table 2 (cont'd)

Descriptive Statistics for Students who Stated Direction by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
	F	9th	3	7	1.2%	2.3%
		10th	5	7	1.9%	2.3%
		11th	120	127	46.5%	42.2%
		Total	128	141	49.6%	46.8%
	x	11th	24	29	9.3%	9.6%
		Total	24	29	9.3%	9.6%
	Total	9th	15	22	5.8%	7.3%
		10th	9	14	3.5%	4.7%
		11th	233	264	90.3%	87.7%
		x	1	1	0.4%	0.3%
		Total	258	301	100.0%	100.0%

As seen by Table 2 above, this is by far the highest answer by receiving 85.71% of all the students' responses. Of the 258, 233 were 11th grade students. When compared by gender 94.48% of the 11th grade were female students and 82.40% were male students using some sort of direction information. The situation was similar regarding the 9th grade students. Twelve of the 15 9th grade students gave information about direction. However, only 3 out of 7 female students gave information about which direction they felt being pushed. Regarding the 10th grade students participating in the test, the number of male and female students who provided direction information was almost equal.

Category: Inertia

After analyzing students answer for question number 1 in part A of the test, below are the results displayed in Table 3 for the category *inertia* by gender and grade level.

Table 3

Descriptive Statistics for Students who Stated Inertia by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Inertia	M	9th	0	15	0.0%	2.3%
		10th	0	7	0.0%	35.9%
		11th	37	108	41.6%	5.0%
		x	0	1	0.0%	0.3%
		Total	37	131	41.6%	43.5%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	42.2%
		11th	47	127	52.8%	2.3%
		Total	47	141	52.8%	46.8%
	x	11th	5	29	5.6%	9.6%
		Total	5	29	5.6%	9.6%
	Total	9th	0	22	0.0%	4.7%
		10th	0	14	0.0%	87.7%
		11th	89	264	100.0%	7.3%
		x	0	1	0.0%	0.3%
		Total	89	301	100.0%	100.0%

The sample who participate in the research consisted of 131 male students (41.6%), 141 female students (52.8%), and 29 students who did not specify their gender (5.6%). As can be seen in Table 2, the overall ratio of male and female students was not equal. So we seem to have a slightly higher percentage of female students over male students in this particular study. In a parallel manner the number of female students using the concept of inertia was higher than the number of male students doing so. None of the 9th and 10th grade students used the concept of inertia. It is particularly interesting and worthwhile to point out that only 11th grade students used the concept of inertia. Of the 301 students surveyed, only 89 (29.56%) in total used the concept of inertia.

Category: Centrifugal Force

Table 4 shows the descriptive statistics results on the second category labeled as centrifugal force by gender and grade level.

Table 4

Descriptive Statistics for Students who Stated Centrifugal Force by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Centrifugal Force	M	9th	0	15	0.0%	5.0%
		10th	4	7	15.4 %	2.3%
		11th	15	108	57.7%	35.9%
		x	0	1	0.0%	0.3%
		Total	19	131	73.1%	43.5%
	F	9th	0	7	0.0%	2.3%
		10th	2	7	7.7%	2.3%
		11th	5	127	19.2%	42.2%
		Total	7	141	26.9%	46.8%
	x	11th	0	29	0.0%	9.6%
		Total	0	29	0.0%	9.6%
Total		9th	0	22	0.0%	4.7%
		10th	6	14	23.1%	4.7%
		11th	20	264	76.9%	87.7%
		x	0	1	0.0%	0.3%
		Total	26	301	100.0%	100.0%

The concept or category of centrifugal force was not used by 9th grade students at all. However, unlike the first category, 10th grade students used the concept of centrifugal force while answering the question. Six out of 14 grade 10 students participating in the survey, 6 responded to the question by using the expression of centrifugal force. Of the 264 11th grade students, only 20 (%7,57) students employed the concept of centrifugal force when answering the question. The concept of centrifugal force is included in the physics curriculum of the 12th grade. Of the 131 male students surveyed, 19 used this concept, while only 7 out of 141 female students used it. The number of male students using the concept of centrifugal force was higher compared to the number of female students. Of the 29 students who did not specify their gender, none used centrifugal force in their explanation.

Category: Force

Descriptive statistics for students who used the concept of force by gender and grade.

Table 5

Descriptive Statistics for Students who Stated Force/Push by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Force/push	M	9th	3	15	14.3%	5.0%
		10th	0	7	0.0%	2.3%
		11th	13	108	61.9%	35.9%
		x	0	1	0.0%	0.3%
		Total	16	131	76.2%	43.5%
	F	9th	0	7	0.0%	2.3%
		10th	1	7	4.8%	2.3%
		11th	3	127	14.3%	42.2%

Table 5 (cont'd)

Descriptive Statistics for Students who Stated Force/Push by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		Total	4	141	19.0%	46.8%
	x	11th	1	29	4.8%	9.6%
		Total	1	29	4.8%	9.6%
	Total	9th	3	22	14.3%	7.3%
		10th	1	14	4.8%	4.7%
		11th	17	264	81.0%	87.7%
		x	0	1	0.0%	0.3%
		Total	21	301	100.0%	100.0%

As shown in the above Table 5, only 21 of the 301 students who participated in the test used the concept of force when answering the question. This makes up about 7% of the students participating in the test. Male students used the concept of force more than female students. While 16 out of 131 male students included the concept of force in their responses, only 4 out of 141 female students answered the question using the concept of force. This is the second least used answer category.

Category: Other

Table 6

Descriptive Statistics for Students who Stated Other by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Other	M	9th	1	15	6.2%	5.0%
		10th	0	7	0.0%	2.3%
		11th	4	108	25.0%	35.9%
		x	0	1	0.0%	0.3%

Table 6 (cont'd)

Descriptive Statistics for Students who Stated Other by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		Total	5	131	31.2%	43.5%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	7	127	43.8%	42.2%
		Total	7	141	43.8%	46.8%
	x	11th	4	29	25.0%	9.6%
		Total	4	29	25.0%	9.6%
	Total	9th	1	22	6.2%	7.3%
		10th	0	14	0.0%	4.7%
		11th	15	264	93.7%	87.7%
		x	0	1	0.0%	0.3%
		Total	16	301	100.0%	100.0%

Sixteen of the 301 students participating in the test provided answers that did not fit in any category listed above. Some of the answers provided by students were thinks like "Air resistance, constant speed of the machine, weight of the person, the surface holding me". It is interesting that the answers were obtained from almost all of the 11th grade students. This is the least answered category.

Category: No Answer

Table 7 shows the descriptive statistics results on the last category labeled as no answer by gender and grade level.

Table 7

Descriptive Statistics for Students who did not Answer the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
No answer	M	9th	3	15	9.4%	5.0%
		10th	2	7	6.2%	2.3%
		11th	11	108	34.4%	35.9%
		x	0	1	0.0%	0.3%
		Total	16	131	50.0%	43.5%
	F	9th	4	7	12.5%	2.3%
		10th	1	7	3.1%	2.3%
		11th	8	127	25.0%	42.2%
		Total	13	141	40.6%	46.8%
	x	11th	3	29	0.0%	9.6%
		Total	3	29	0.0%	9.6%
	Total	9th	7	22	21.9%	7.3%
		10th	3	14	9.4%	4.7%
		11th	22	264	68.7%	87.7%
		x	0	1	0.0%	0.3%
		Total	32	301	100.0%	100.0%

As can be seen from Table 7, a total of 32 (10.63%) failed to provide an answer. Given the fact that inertial and non-inertial reference frames are difficult concepts to teach one can consider this to be a surprisingly low percentage. It seems that students made an effort to provide some sort of an answer. There were students from all grades who did not answer the questions. When compared by gender16 were male and 13 were female students. Of the 29 students who did not specify gender, 3 failed to provide an answer.

Answers and Results for Question Number 2 Part A

The second test question was "Imagine yourself sitting on an accelerating bus, facing forward. In which direction do you feel yourself being pushed? Why? Then what prevents our motion in that direction?" Statistical information about this question is given in Table 8, Table 9, Table 10, Table 11, and Table 12

Category: Backward

Table 8 shows the descriptive statistics results on the first category of question number 2 labeled as backward by gender and grade level.

Table 8

Descriptive Statistics for Students who Stated Backward by Gender and Grade Level

Category	Grade	Gender	Sum	N	Total Sum %	Total N%
Backward	9th	M	12	15	5.2%	5.0%
		F	1	6	0,4%	2.0%
		Total	13	21	5,7%	7,0%
	10th	M	5	7	2,2%	2,3%
		F	5	7	2,2%	2,3%
		Total	10	14	4,4%	4.7%
	11th	M	85	108	37,1%	35,9%
		F	98	128	42,8%	42,5%
		x	22	29	9.6%	9.6%
		Total	205	265	89,5%	88,0%
	x	M	1	1	0,4%	0,3%
		Total	1	1	0,4%	0,3%
		M	103	131	45,0%	43,5%
		F	104	141	45,4%	46,8%
		x	22	29	9.6%	9.6%
		Total	229	301	100.0%	100.0%

As can be seen from Table 8 above, 229 (76%) of the 301 students answered that they felt pushed backward when the bus would accelerate forward. It is noteworthy to mention that 9^{th} grade students were able to provide an answer this time. 10 of the 14 students at the 10th grade noted that they were pushed back, similarly 13 of 21 students at the 9th grade stated they were pushed backward. An overwhelming number juniors that is, 77.35% of the 11th graders' answered that they felt pushed backward. The gender ratio came out to be balanced, 78.62% of the male versus 73.75% of the female students noted that they were pushed towards the back.

Category: Inertia

Table 9 shows the descriptive statistics results on the second category of question number 2 labeled as inertia by gender and grade level.

Table 9

Descriptive Statistics for Students who Stated Inertia by Gender and Grade Level

Category	Grade	Gender	Sum	N	Total Sum %	Total N%
		M	0	15	0,0%	5.0%
	9th	F	0	6	0,0%	2.0%
		Total	0	21	0,0%	7,0%
		M	0	7	0,0%	2,3%
	10th	F	0	7	0,0%	2,3%
		Total	0	14	0,0%	4.7%
Inertia		M	55	108	39,6%	35,9%
	11th	F	68	128	48,9%	42,5%
		x	16	29	11.5%	9.6%
		Total	139	265	100.0%	88,0%
		M	55	131	39,6%	43,5%
	Total	F	68	141	48,9%	46,8%
		x	16	29	11.5%	9.6%
		Total	139	301	100.0%	100.0%

As seen from Table 9, 139 (46.17%) of all the students who participated in test explained the reason for the event mentioned in the question by using the concept of inertia. While none of the test participants from 9th and 10th grade used the concept of inertia, 52.45% of the 11th grade participants explained the question with the concept of inertia. 48.22% female students and a slightly less number of male students (41.98%) used the concept of inertia.

Category: Forward

Table 10 shows the descriptive statistics results on the fourth category of question number 2 labeled as forward by gender and grade level.

Table 10

Descriptive Statistics for Students who Stated Backward by Gender and Grade Level

Category	Grade	Gender	Sum	N	Total Sum %	Total N%
Forward	9th	M	2	15	3.3%	5.0%
		F	4	6	6,7%	2.0%
		Total	6	21	10.0%	7,0%
	10th	M	0	7	0,0%	2,3%
		F	1	7	1,7%	2,3%
		Total	1	14	1,7%	4.7%
	11th	M	15	108	39,6%	35,9%
		F	32	128	48,9%	42,5%
		x	6	29	25.0%	35,9%
		Total	53	265	53,3%	42,5%
	x	M	0	1	0,0%	0,3%
		Total	0	1	0,0%	0,3%
	Total	M	17	131	28,3%	43,5%
		F	37	141	61,7%	46,8%
		x	6	29	10,0%	9,6%
		Total	60	301	100,0%	100,0%

As seen from Table 10, 60 (19.93%) of all the 301 students stated they felt being pushed forward in the accelerating bus. Only 1 of the 14 students at the 10th grade noted that she felt being pushed forward. Six of 21 students at the 9th grade stated that they were pushed forward in a bus accelerating forward. 20% of the students surveyed at the 11th grade said they felt pushed forward. When compared by gender half of the male students (12.97%) felt pushed forward, while 26.24% of the female students stated they felt being pushed forward. Note that the only answer of the 9th grade student is also female.

Category: Bus Seat

Table 11 shows the descriptive statistics results on the third category of question number 2 labeled as bus seat by gender and grade level

Table 11

Descriptive Statistics for Students who Stated Bus Seat by Gender and Grade Level

Category	Grade	Gender	Sum	N	Total Sum %	Total N%
Bus seat	9th	M	1	15	4,5%	5.0%
		F	1	6	4,5%	2.0%
		Total	2	21	9.1%	7,0%
	10th	M	0	7	0,0%	2,3%
		F	0	7	0,0%	2,3%
		Total	0	14	0,0%	4.7%
	11th	M	12	108	54,5%	35,9%
		F	6	128	27,3%	42,5%
		x	2	29	9,1%	9,6%
		Total	20	265	90,9%	88,0%
	x	M	0	1	0,0%	0,3%
		Total	0	1	0,0%	0,3%

Table 11 (cont'd)

Descriptive Statistics for Students who Stated Bus Seat by Gender and Grade Level

Category	Grade	Gender	Sum	N	Total Sum %	Total N%
		M	13	131	59,1%	43,5%
	Total	F	7	141	31,8%	46,8%
		x	2	29	9,1%	9,6%
		Total	22	301	100,0%	100,0%

As seen from Table 11, 22 (7.3%) of the 301 participants explained the factor that prevented their motion, that is, movement as the reason of the bus seat. While none of the respondents from 10th grade mentioned the bus seat, only two of the 9th grade students used this word. Similarly, 7.54% of the 11th grade students explained the question with the bus seat. The number of male students (9.92%) using the word bus seat was higher than female students who used it (4.96%).

Category: No Answer

Table 12 shows the descriptive statistics results on the fifth category of question number 2 labeled as no answer by gender and grade level

Table 12

Descriptive Statistics for Students who did not Answer the Question by Gender and Grade Level

Category	Grade	Gender	Sum	N	Total Sum %	Total N%
		M	1	15	4,5%	5.0%
	9th	F	1	6	4,5%	2.0%
		Total	2	21	9.1%	7,0%
		M	0	7	0,0%	2,3%
	10th	F	0	7	0,0%	2,3%
		Total	0	14	0,0%	4.7%

Table 12 (cont'd)

Descriptive Statistics for Students who did not Answer the Question by Gender and Grade Level

Category	Grade	Gender	Sum	N	Total Sum %	Total N%
		M	12	108	54,5%	35,9%
		F	6	128	27,3%	42,5%
	11th	x	2	29	9.1%	9.6%
		Total	20	265	90,9%	88,0%
	x	M	0	1	0,0%	0,3%
		Total	0	1	0,0%	0,3%
		M	13	131	59.1%	43,5%
	Total	F	7	141	31,8%	46,8%
		x	2	29	9.1%	9.6%
		Total	22	301	100.0%	100.0%

As can be seen from Table 12, the number of students who did not answer the second question in the questionnaire constituted 22 (7.30%) students. This seemed to be a slightly easier question when compared with question number 1. While all 10th grade participants answered the question, two students at the 9th grade did not respond to the question. The numbers listed here are that did not answer. So a zero refers to the total number of student that did not answer. 20 the 11th grade students failed to make any comments. The number of male students (n=13) who did not answer the question was slightly higher than the that of female students (n=7).

Answers and Results for Question Number 3 Part A

The third question was "It is said that motion is relative. For example, on the earth's frame of reference, the sun moves across the sky each day from east to west; while in the sun's frame of reference the earth rotates around its axis. Yet we insist that the motion of the sun around the earth is apparent, and it is the earth that actually rotates. What is the basis of this preference? (Please ignore the presence of other planets in the solar system.)". The following section provided descriptive statistical results regarding the categorical answers provided by the students. Table 20 demonstrate that this question was perceived as one of the difficult ones, because more the half of the students chose not to answer or avoided to provide an answer.

Category: We are on the Earth

Table 13 shows the descriptive statistics results on the category of question number 3 labeled as we are on the earth by gender and grade level.

Table 13

Descriptive Statistics for Students who Stated We are on the Earth the Question by Gender and Grade level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
We are on the earth	M	9th	1	15	3.4%	5.0%
		10th	0	7	0.0%	2.3%
		11th	17	107	58.6%	35.7%
		x	0	1	0.0%	0.3%
		Total	18	130	62.1%	43.3%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	11	127	37.9%	42.3%
		Total	11	141	37.9%	47.0%
	x	11th	0	29	0.0%	9.7%
		Total	0	29	0.0%	9.7%
	Total	9th	1	22	3.4%	7.3%
		10th	0	14	0.0%	4.7%
		11th	28	263	96.6%	87.7%
		x	0	1	0.0%	0.3%
		Total	29	300	100%	100%

As shown Table 13, 29 students (9.66%) out of 300 rationalized the reference selection as we are on the earth. Students who agree that idea are generally 11th grade students. When gender was considered, the distribution was quite similar; 11 female and 17 male students responded. So there seems no significant indication of gender difference.

Category: Rotation

Table 14 shows the descriptive statistics results on the third category of question number 3 labeled as related to rotation of the sun and the earth by gender and grade level.

Table 14

Descriptive Statistics for Students who Stated We are on the Earth the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Rotation of the Sun and the Earth	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	6	107	20.7%	35.7%
		x	0	1	0.0%	0.3%
		Total	6	130	20.7%	43.3%
		9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	22	127	75.9%	42.3%
		Total	22	141	75.9%	47
	x	11th	1	29	3.4%	9.7%
		Total	1	29	3.4%	9.7%
	Total	9th	0	22	0.0%	7.3%
		10th	0	14	0.0%	4.7%
		11th	29	263	100%	87.7%
		x	0	1	0.0%	0.3%
		Total	29	300	100%	100%

As shown in Table 14, 29 students (9.66%) of the 300 indicated the rotation of the earth around its own axis, the rotation of the sun around the earth, the formation of night and day is the cause of reference. While again none of the 9th and 10th grade students had an answer. The interesting point was that most of the juniors 22 out of 29 (75.86%) were female.

Category: Size

Table 15 shows the descriptive statistics results on the fourth category of question number 3 labeled as size by gender and grade.

Table 15

Descriptive Statistics for Students who Stated Size the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Size	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	14	107	50.0%	35.7%
		x	0	1	0.0%	0.3%
		Total	14	130	50.0%	43.3%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	10	127	35.7%	42.3%
		Total	10	141	35.7%	47.0%
	x	11th	4	29	14.3%	9.7%
		Total	4	29	14.3%	9.7%
	Total	9th	0	22	0.0%	7.3%
		10th	0	14	0.0%	4.7%
		11th	28	263	100%	87.7%
		x	0	1	0.0%	0.3%
		Total	28	300	100%	100%

As shown in Table 15, 28 students (9.33%) out of 300 attributed the reason of taking the reference as a basis to the fact that the sun is dimensionally larger. Again none of the 9th and 10th grade-students answered the question. But on the contrary to the category “the sun and the earth”, the gender difference for this category was somewhat balanced - 14 male versus 10 females.

Category: Copernicus Thesis

Table 16 shows the descriptive statistics results on the category of question number 3 labeled as Copernicus thesis by gender and grade.

Table 16

Descriptive Statistics for Students who Stated Size the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Copernicus thesis	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	7	107	26.9%	35.7%
		x	0	1	0.0%	0.3%
		Total	7	130	26.9%	43.3%
	F	9th	1	7	3.8%	2.3%
		10th	0	7	0.0%	2.3%
		11th	16	127	61.5%	42.3%
		Total	17	141	65.4%	47.0%
	x	11th	2	29	7.7%	9.7%
		Total	2	29	7.7%	9.7%
	Total	9th	1	22	3.8%	7.3%
		10th	0	14	0.0%	4.7%
		11th	25	263	96.2%	87.7%
		x	0	1	0.0%	0.3%
		Total	26	300	100%	100%

As shown in Table 16, 26 students out of 300 (8.66%) used a rational such as the Copernican theory. While none of the 10th grade students used the Copernican theory, only 1 of the 9th grade-level participants used this expression. 25 (9.50%) of 263 11th grade-level participants answered the question by using the Copernicus thesis. The ratio of female students (n=17) using the Copernicus thesis was approximately 2.5 times higher than the number of male students (n=7).

Category: Absolute Reference

Table 17 shows the descriptive statistics results on the fifth category of question number 3 labeled as absolute reference by gender and grade.

Table 17

Descriptive Statistics for Students who Stated Absolute Reference the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Absolute reference	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	7	107	26.9%	35.7%
		x	0	1	0.0%	0.3%
		Total	7	130	26.9%	43.3%
	F	9th	1	7	3.8%	2.3%
		10th	0	7	0.0%	2.3%
		11th	16	127	61.5%	42.3%
		Total	17	141	65.4%	47.0%
	x	11th	2	29	7.7%	9.7%
		Total	2	29	7.7%	9.7%
	Total	9th	1	22	5.6%	7.3%
		10th	0	14	0.0%	4.7%
		11th	17	263	94.4%	87.7%
		x	0	1	0.0%	0.3%
		Total	18	300	100%	100%

As shown in Table 17, a total of 18 students believed and explained that the reference was absolute, in other words fixed. With such a low number, we can deduce that the students have a fairly good understanding that motion in some sense is relative. That is, it seems that students were aware that the reference frames can be chosen. When gender was considered, the distribution was equal because 8 female and 8 male students responded. So there seems no significant indication of gender difference.

Category: Gravitational Force Between the Sun and the Earth

Table 18 shows the descriptive statistics results on the first category of question number 3 labeled as Gravitational force between the sun and the earth by gender and grade level.

Table 18

Descriptive Statistics for Students who Stated Gravitational Force Between the Sun and the Earth the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Gravitational force between the sun and the earth	M	9th	0	15	0,0%	5,0%
		10th	0	7	0,0%	2,3%
		11th	3	107	75,0%	35,7%
		x	0	1	0,0%	0,3%
		Total	3	130	75,0%	43,3%
	F	9th	0	7	0,0%	2,3%
		10th	0	7	0,0%	2,3%
		11th	1	127	25,0%	42,3%
		Total	1	141	25,0%	47,0%
	x	11th	0	29	0,0%	9,7%
		Total	0	29	0,0%	9,7%

Table 18 (cont'd)

Descriptive Statistics for Students who Stated Gravitational Force Between the Sun and the Earth the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	0	22	0,0%	7,3%
		10th	0	14	0,0%	4,7%
		11th	4	263	100,0%	87,7%
		x	0	1	0,0%	0,3%
		Total	4	300	100,0%	100,0%

As shown in Table 18, only 4 students (1.3%) out of 300 responded with an answer relating gravitational force. So basically four students believed that the gravitation force was the cause or preference for the reference. All of the answers were given by 11th grade (junior) students. At this point there is no meaningful data resulting in a possible discussion or comparison as far as gender is concerned.

Category: Related to Mass and Dimension

Table 19 shows the descriptive statistics results on the second category of question number 3 labeled as related to mass and dimension by gender and grade level.

Table 19

Descriptive Statistics for Students who Stated Mass and Dimension the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	0	15	0,0%	5,0%
	M	10th	0	7	0,0%	2,3%
		11th	1	107	100,0%	35,7%

Table 19 (cont'd)

Descriptive Statistics for Students who Stated Mass and Dimension the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Mass and Dimension	M	x	0	1	0,0%	0,3%
		Total	1	130	100,0%	43,3%
	F	9th	0	7	0,0%	2,3%
		10th	0	7	0,0%	2,3%
		11th	0	127	0,0%	42,3%
		Total	0	141	0,0%	47,0%
	x	11th	0	29	0,0%	9,7%
		Total	0	29	0,0%	9,7%
	Total	9th	0	22	0,0%	7,3%
		10th	0	14	0,0%	4,7%
		11th	1	263	100,0%	87,7%
		x	0	1	0,0%	0,3%
		Total	1	300	100,0%	100,0%

As shown in Table 19, only 1 student out of 300 responded with an answer related to mass and dimension. Therefore, only one student believed that related to mass and dimension was the cause or preference for the reference. Again the answers were given by 11^{th} grade (junior) students. At this point there is no meaningful data resulting in a possible discussion or comparison as far as gender is concerned.

Category: No Answer

Table 20 shows the descriptive statistics results on the category of question number 3 labeled as no answer by gender and grade level.

Table 20

Descriptive Statistics for Students who did not Answer the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	12	15	6.7%	5.1%
		10th	7	7	3.9%	2.4%
	M	11th	54	106	30%	36.1%
		x	1	1	0.6%	0.3%
		Total	74	129	41.1%	43.9%
		9th	7	7	3.9%	2.4%
		10th	7	7	3.9%	2.4%
	F	11th	71	122	39.4%	41.5%
		Total	85	136	47.2%	46.3%
	x	11th	21	29	11.7%	9.9%
No answer		Total	21	29	11.7%	9.9%
		9th	19	22	10.6%	7.5%
		10th	14	14	7.8%	4.8%
	Total	11th	146	257	81.1%	87.4%
		x	1	1	0,0%	0,3%
		Total	180	300	100,0%	100,0%

As shown in Table 20, almost two thirds that is 180 out of 294 students had no answer. So clearly this was one of the hardest questions on the test. As can be seen from the table, the majority of 9th and 10th grade students failed to answer. But what was surprising being that juniors were also not able to answer. As far as gender was concerned, 85 female students out of 136 did not answer the question (62.50%). For male it was 74 out of 129 (57.36%), as shown in the table above.

Answers and Results for Question Number 4 Part A

The fourth question was, "A child is sitting in a rotating merry- go – round and a man is standing on the ground. In the ground's frame of reference, is there a centrifugal force on the child? In the child's frame of reference, is there a centrifugal force on the man? Explain. Statistical information about this question is given in tables 21 to 25.

Category: There was a CF on the Child

Table 21 shows the descriptive statistics results on the category of question number 4 labeled as there was a centrifugal force (C.F.) on the child by gender and grade level.

Table 21

Descriptive Statistics for Students who Stated There was a C.F. on the Child the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
There was a C.F. on the child	M	9th	3	15	2.0%	5.0%
		10th	2	7	1.3%	2.3%
		11th	60	108	39.2%	36.1%
		x	0	1	0.0%	0.3%
		Total	65	131	42.5%	43.8%
	F	9th	5	7	3.3%	2.3%
		10th	0	7	0.0%	2.3%
		11th	65	125	42.5%	41.8%
		Total	70	139	45.8%	46.5%
	x	11th	18	29	11.8%	9.7%
		Total	18	29	11.8%	9.7%

Table 21 (cont'd)

Descriptive Statistics for Students who Stated There was a C.F. on the Child the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	8	22	5.2%	7.4%
		10th	2	14	1.3%	4.7%
	Total	11th	143	262	93.5%	87.6%
		x	0	1	0.0%	0.3%
		Total	153	299	100.0%	100.0%

As shown in Table 21, slightly more than half of the students, that is 153 students out of 299 stated that there was a centrifugal force on the child. The majority of the student body who responded were again juniors. Unlike question 3, there were relatively less grade 9 and 10 student who responded question 4. The number of male and female students who express the centrifugal force on the child was almost equal. While 8 out of 22 students at the 9th-grade stated that the child had centrifugal force on him, only 4 out of 14 10th grade students answered the question by saying that there is a centrifugal force on the child. In contrast, 143 of 262 11th grade students stated that the child had centrifugal force on him. As stated above this ratio constituted approximately 55% of the 11th-grade students.

Category: Centrifugal Force on the Man

Table 22 shows the descriptive statistical result of students' who said that there was a centrifugal force on the man based by gender and grade.

Table 22

Descriptive Statistics for Students who State There was a C.F. on the Man by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
There was a C.F. on the man	M	9th	4	15	4.0%	5.0%
		10th	2	7	2.0%	2.3%
		11th	33	108	33.3%	35.9%
		x	1	1	1.0%	0.3%
		Total	40	131	40.4%	43.5%
	F	9th	3	7	3.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	41	127	41.4%	42.2%
		Total	44	141	44.4%	46.8%
	x	11th	15	29	15.2%	9.6%
		Total	15	29	15.2%	9.6%
	Total	9th	7	22	7.1%	7.3%
		10th	2	14	2.0%	4.7%
		11th	89	264	89.9%	87.7%
		x	1	1	0.0%	0.3%
		Total	99	299	100.0%	100.0%

As seen in Table 23, almost one third, that is 99 students out of 301 answered that there would be a centrifugal force on the man sitting on the ground. Fourty out of 131 male stated that the man had centrifugal force on him, 44 out of the 141 female students stated that there was a centrifugal force on the man. The number of male and female students who express there was a centrifugal force on the man again seems to be almost equal. While 7 out of 22 students at the 9th-grade stated a centrifugal force on the man, only 2 out of 14 grade 10 students answered the question by saying that there was a centrifugal force on the man. Once again, it can be conclude that the freshmen and sophomore students' answers were relatively low. In comparison, 89 of 264 11th grade students stated that the man had centrifugal force on him. This ratio constituted approximately 33% of the 11th-grade students body.

Category: No CF on Man

Descriptive statistical result of students' who said that there was no centrifugal force on the man sitting on ground based by gender and grade.

Table 23

Descriptive Statistics for Students who Stated There was a no C.F. on the Man by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
There was a no C.F. on the man	M	9th	4	15	4.2%	5.0%
		10th	2	7	2.1%	2.3%
		11th	42	108	44.2%	35.9%
		x	0	1	0.0%	0.3%
		Total	48	131	50.5%	43.5%
		9th	1	7	1.1%	2.3%
		10th	0	7	0.0%	2.3%
		11th	40	127	42.1%	42.2%
		Total	41	141	43.2%	46.8%
	x	11th	6	29	6.3%	9.6%
		Total	6	29	6.3%	9.6%
	Total	9th	5	22	5.3%	7.3%
		10th	2	14	2.1%	4.7%
		11th	88	264	92.6%	87.7%
		x	0	1	0.0%	0.3%
		Total	95	299	100.0%	100.0%

As shown in Table 23 above, almost one third, that is 95 students out of 301 answered that there would be no centrifugal force on the man sitting on the ground. When compared with the results provided in table 24, that is the previous answer, it seems that the opinion of the study body was split. 48 of 131 males and 41 of 141 female students stated that the man had no centrifugal force on him. For this scenario the male student numbers were slightly more than that of female students. The freshmen and sophomore answer ratio was similar as the previous answers. The numbers were 5 out of 22 students for 9th grade and only 2 of the 14 10th grade students. The majority of the answers were provided by the juniors, 88 of 264 11th grade students which account approximately to 33% of the 11th-grade students.

Category: There was no CF on the Child

Table 24 shows the descriptive statistics results on the category of question number 4 labeled as there was no centrifugal force (C.F.) on the child by gender and grade level.

Table 24

Descriptive Statistics for Students who Stated There was a no C.F. on the Child by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	3	15	6.1%	5.0%
	M	10th	1	7	2.0%	2.3%
		11th	17	108	34.7%	35.9%
		x	1	1	2.0%	0.3%
		Total	22	131	44.9%	43.5%
		9th	1	7	2.0%	2.3%
There was NO	F	10th	0	7	0.0%	2.3%
C. F. on the		11th	21	127	42.9%	42.2%
Child		Total	22	141	44.9%	46.8%

Table 24 (cont'd)

Descriptive Statistics for Students who Stated There was a no C.F. on the Child by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
	x	11th	5	29	10.2%	9.6%
		Total	5	29	10.2%	9.6%
		9th	4	22	8.2%	7.3%
		10th	1	14	2.0%	4.7%
	Total	11th	43	264	87.8%	87.7%
		x	1	1	2.0%	0.3%
		Total	49	301	100.0%	100.0%

As shown in Table 24, there was not surprisingly a significant drop in answers. A total of 49 students out of 301 claimed that there was no C.F. on the child. 9th and 10th grade students seemed again to be conservative with a large percentage not expression their opinion in this category. students 22 of 131 male students who participated in the questionnaire from 9th, 10th, and 11th-grade levels stated no centrifugal force on the child, the same number of participants out of 141 of the female students stated that there was no centrifugal force on the child. When gender was considered, the distribution was quite similar; 21 female and 17 male students responded. Considering that the sample had some slightly larger female students we can safely say that there seemed no significant indication of gender difference.

Category: No Answer

Table 25 shows the descriptive statistics results on the category of question number 4 labeled as no answer by gender and grade.

Table 25

Descriptive Statistics for Students who did not Answer the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
No answer	M	9th	7	15	7,4%	5,0%
		10th	3	7	3,2%	2,3%
		11th	31	108	32,6%	35,9%
		x	0	1	0,0%	0,3%
		Total	41	131	43,2%	43,5%
	F	9th	1	7	1,1%	2,3%
		10th	7	7	7,4%	2,3%
		11th	40	127	42,1%	42,2%
		Total	48	141	50,5%	46,8%
	x	11th	6	29	6,3%	9,6%
		Total	6	29	6,3%	9,6%
	Total	9th	8	22	8,4%	7,3%
		10th	10	14	10,5%	4,7%
		11th	77	264	81,1%	87,7%
		x	0	1	0,0%	0,3%
		Total	95	301	100,0%	100,0%

As seen in Table 25 above, there were students from all the grades who did not answer the questions. As usual the junior students were the once who provided an answer. For this particular case we have observed a balanced distribution of among the junior student body. One third, that is 95 students out of 301 did not answer. When considering the gender differences, we again observe a balanced distribution. The numbers were 41 out of 131 (31.29%) male students and 48 out 141 (34.04%) of female students did not answer the question.

Answers and Results for Question Number 5 Part A

The fifth question was, "A train is moving uniformly. A ball rests on the floor of the train. If the train slows down suddenly, describe and explain the motion of the ball both from the point of view of an observer inside the train and an observer on the ground. Ignore friction. Statistical results regarding the analyses on this question were given in Tables 26 through 34.

Category: Forward Inside the Train

Table 26 shows the descriptive statistics results on the category of question number 5 labeled describing the motion of the ball as forward from the point of view of an observer inside the train by gender and grade.

Table 26

Descriptive Statistics for Students who Stated Forward (Inside the Train) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Forward (inside the train)	M	9th	7	15	5.4%	5.0%
		10th	2	7	1.5%	2.3%
		11th	63	108	48.5%	36.0%
		x	0	1	0.0%	0.3%
		Total	72	131	55.4%	43.7%
	F	9th	2	7	1.5%	2.3%
		10th	1	7	0.8%	2.3%
		11th	42	126	32.3%	42.0%
		Total	45	140	34.6%	46.7%
	x	11th	13	29	10.0%	9.7%
		Total	13	29	10.0%	9.7%

Table 26 (cont'd)

Descriptive Statistics for Students who Stated Forward (Inside the Train) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	9	22	6.9%	7.3%
		10th	3	14	2.3%	4.7%
	Total	11th	118	263	90.8%	87.7%
		x	0	1	0,0%	0,3%
		Total	130	301	100,0%	100,0%

As seen in Table 26 above, a significant number of students (n=130;43.33%) wrote that the ball on a train moving at a constant speed will move forward according to the observer inside the train when the train starts to slow down. Even freshmen and sophomore students opinioned their thought. 3 of the 14 10th grade students and 9 of the 22 9th grade students agreed with the juniors. 44.86% of the 11th grade participants stated that the movement of the ball would be forward. When considering the gender differences, we observed a slight higher ratio in favor of males. The numbers were 54.96% for male students and 32.14% for female students.

Category: Forward (Ground Observer)

Table 27 shows the descriptive statistics results on the category of question number 5 labeled as forward from the point of view of a ground observer outside of the train by gender and grade.

Table 27

Descriptive Statistics for Students who Stated Forward (Ground Observer) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Forward (ground observer)	M	9th	7	15	5.8%	5.0%
		10th	2	7	1.7%	2.3%
		11th	54	108	44.6%	36.0%
		x	1	1	0.8%	0.3%
		Total	64	131	52.9%	43.7%
	F	9th	1	7	0.8%	2.3%
		10th	1	7	0.8%	2.3%
		11th	44	126	36.4%	42.0%
		Total	46	140	38.0%	46.7%
	x	11th	11	29	9.1%	9.7%
		Total	11	29	9.1%	9.7%
	Total	9th	8	22	6.6%	7.3%
		10th	3	14	2.5%	4.7%
		11th	109	263	90.1%	87.7%
		x	1	1	0.8%	0.3%
		Total	121	300	100.0%	100.0%

As seen in Table 27 above, 40.33% that is 121 students out of 300 stated that the ball inside the slowing train would be seen moving forward according to the observer outside. While only 3 of the 10th grade participants answered the question in this way, surprisingly the majority that is 8 of the 9th grade participants gave this answer. When considering the gender differences, we observe a slightly higher percentage of 48.85% male students over female students 32.85%.

Category: Backwards (Inside the Train)

Table 28 shows the descriptive statistics results on the category of question number 5 labeled as backwards from the point of view of an observer inside the train by gender and grade.

Table 28

Descriptive Statistics for Students Who Stated Backwards (Observer Inside the Train) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Backwards (observer inside the train)	M	9th	3	15	9.4%	5.0%
		10th	0	7	0.0%	2.3%
		11th	5	108	15.6%	36.0%
		x	1	1	3.1%	0.3%
		Total	9	131	28.1%	43.7%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	18	126	56.2%	42.0%
		Total	18	18	140	56.2%
	x	11th	5	29	15.6%	9.7%
		Total	5	29	15.6%	9.7%
	Total	9th	3	22	9.4%	7.3%
		10th	0	14	0.0%	4.7%
		11th	28	263	87.5%	87.7%
		x	1	1	3.1%	0.3%
		Total	32	300	100.0%	100.0%

As seen in Table 28 above, only 32 students (10.66%) stated that the ball inside the train moving at a constant speed will move backward according to the observer on the train when the train slows down. While no students from the 10th grade expressed this view, 3 of the 9th grade students stated it would move backward. Twice the number of female students (n=18; 12.85%) over male students (n=9; 6.87%) responded with this belief.

Category: Backwards (Ground Observer)

Table 29 shows the descriptive statistics results on the category of question number 5 labeled as backwards from the point of view of a ground observer outside the train by gender and grade.

Table 29

Descriptive Statistics for Students who Stated Forward (Ground Observer) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Backwards (ground observer)	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	5	108	16.7%	36.0%
		x	0	1	0.0%	0.3%
		Total	5	131	16.7%	43.7%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	19	126	63.3%	42.0%
		Total	19	140	63.3%	46.7%
	x	11th	6	29	20.0%	9.7%
		Total	6	29	20.0%	9.7%
	Total	9th	0	22	0.0%	7.3%
		10th	0	14	0.0%	4.7%
		11th	30	263	100.0%	87.7%
		x	0	1	0.0%	0.3%
		Total	30	300	100.0%	100.0%

As seen in Table 29 above, only 10% of the total student body stated that the ball inside the slowing train would go backwards when observed outside the train. None of the 10th and 9th grades answered the question. The sharp drop in the number of answers seems to be due to general misconceptions of motion student hold. Interestingly we found that female students responded significantly higher than male students.

Category: Steady (Inside the Train)

Table 30 shows the descriptive statistics results on the category of question number 5 labeled steady motion seen from the point of view of an observer inside the train by gender and grade.

Table 30

Descriptive Statistics for Students who Stated Steady (Observer Inside the Train) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Steady (inside the train)	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	11	108	44.0%	36.0%
		x	0	1	0.0%	0.3%
		Total	11	131	44.0%	43.7%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	11	126	44.0%	42.0%
		Total	11	140	44.0%	46.7%
	x	11th	3	29	12.0%	9.7%
		Total	3	29	12.0%	9.7%

Table 30 (cont'd)

Descriptive Statistics for Students who Stated Steady (Observer Inside the Train) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	0	22	0.0%	7.3%
		10th	0	14	0.0%	4.7%
	Total	11th	25	263	100.0%	87.7%
		x	0	1	0.0%	0.3%
		Total	25	300	100.0%	100.0%

As seen in Table 30 above, 25 (8.33%) out of 300 students stated that the ball in the slowing train would remain steady seen by an observer located inside the train. While none of the 9th and 10th grade students answered the question. When considering the gender differences, we again observe a balanced distribution; 8.39% male students versus 7.85% female students.

Category: Steady Ground Observer

Table 31 shows the descriptive statistics results on the category of question number 5 labeled as steady from the point of view of a ground observer outside the train by gender and grade.

Table 31

Descriptive Statistics for Students who Stated Steady (Ground Observer) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	1	15	4.2%	5.0%
	M	10th	0	7	0.0%	2.3%
		11th	12	108	50.0%	36.0%

Table 31 (cont'd)

Descriptive Statistics for Students who Stated Steady (Ground Observer) by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
	M	x	0	1	0.0%	0.3%
		Total	13	131	54.2%	43.7%
		9th	0	7	0.0%	2.3%
	F	10th	0	7	0.0%	2.3%
		11th	9	126	37.5%	42.0%
		Total	9	140	37.5%	46.7%
	x	11th	5	29	10.2%	9.6%
		Total	5	29	10.2%	9.6%
		9th	4	22	8.2%	7.3%
		10th	1	14	2.0%	4.7%
	Total	11th	43	264	87.8%	87.7%
		x	1	1	2.0%	0.3%
		Total	49	301	100.0%	100.0%

As seen in Table 31 above, only about 24 (8%) of the 300 students stated that the ball inside the slowing train would remain steady according to the ground observer outside the train. Clearly not a very plausible answer for the majority of the student body. Again, none of the 10th grade students and only 1 of the 9th grade student answered the question. When considering the gender differences, we again observe a what could be labeled as a balanced distribution within the context of this study (nfemale=9; nmale=13).

Category: Inertia

Table 32 shows the descriptive statistics results on the category of question number 5 labeled as inertia by gender and grade.

Table 32

Descriptive Statistics for Students who Stated Inertia by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Inertia	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	9	108	47.4%	36.0%
		x	0	1	0.0%	0.3%
		Total	9	131	47.4%	43.7%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	7	126	36.8%	42.0%
		Total	7	140	36.8%	46.7%
	x	11th	3	29	15.8%	9.7%
		Total	3	29	15.8%	9.7%
	Total	9th	0	22	0.0%	7.3%
		10th	0	14	0.0%	4.7%
		11th	19	263	100.0%	87.7%
		x	0	1	0.0%	0.3%
		Total	19	300	100.0%	100.0%

As seen in Table 32 above, none of the 9th and 10th grade students used the concept of inertia when answering the question. 7.22% of the 11th grade students used the concept of inertia while answering the question. When considering the gender differences, we again observe a balanced distribution – 7 female and 9 male students.

Category: Relative Motion

Table 33 shows the descriptive statistics results on the category of question number 5 labeled as relative motion by gender and grade.

Table 33

Descriptive Statistics for Students who Stated Relative Motion by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Relative motion	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	6	108	60.0%	36.0%
		x	0	1	0.0%	0.3%
		Total	6	131	60.0%	43.7%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	4	126	40.0%	42.0%
		Total	4	140	40.0%	46.7%
	x	11th	0	29	0.0%	9.7%
		Total	0	29	0.0%	9.7%
	Total	9th	0	22	0.0%	7.3%
		10th	0	14	0.0%	4.7%
		11th	10	263	100.0%	87.7%
		x	0	1	0.0%	0.3%
		Total	10	300	100.0%	100.0%

As seen in Table 33 above, only 10 students out of 300 attributed the motion of the ball to the concept of relative motion. This student number amounted to only 3.33% of the total student body. While again none of the 9th and 10th grade students used this concept. When considering the gender differences, we again observe a balanced distribution – 4 female and 6 male students.

Category: No Answer

Descriptive statistics for students who did not answer the question by gender and grade.

Table 34

Descriptive Statistics for Students who did not Answer the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
No answer	M	9th	5	15	6.0%	5.0%
		10th	5	7	6.0%	2.3%
		11th	27	108	32.1%	36.0%
		x	0	1	0.0%	0.3%
		Total	37	131	44.0%	43.7%
	F	9th	5	7	6.0%	2.3%
		10th	5	7	6.0%	2.3%
		11th	33	126	39.3%	42.0%
		Total	43	140	51.2%	46.7%
	x	11th	4	29	4.8%	9.7%
		Total	4	29	4.8%	9.7%
	Total	9th	10	22	11.9%	7.3%
		10th	10	14	11.9%	4.7%
		11th	64	263	76.2%	87.7%
		x	0	1	0.0%	0.3%
		Total	84	300	100.0%	100.0%

As seen in Table 34 above, 84 (28%) students did not answer the question. While the majority of the 10th grade students did not answer the question, Half of the 9th grade students did try and the other half did not answer the question. Although relative motion subject is included in the beginning of the 11th grade curriculum, 24.33% of the 11th grade students did not answer the question. When considering the gender differences, we again observe a balanced distribution – 43 female and 37 male students

Answers and Results for Question Number 6 Part A

The sixth question was “A stone is tied to a string and rotated uniformly in a horizontal circle. Is the following statement true? The tension in the string and the centrifugal force on the stone are equal and opposite, and therefore keep the stone in equilibrium’ Statistical information on this question is given in Table 35 to 37.

Category: True

Descriptive statistics for students who stated true for the statement by gender and grade.

Table 35

Descriptive Statistics for Students who Stated True by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
True	M	9th	7	15	3.8%	5.0%
		10th	6	7	3.3%	2.3%
		11th	65	108	35.5%	36.0%
		x	0	1	0.0%	0.3%
		Total	78	131	42.6%	43.7%
	F	9th	4	7	2.2%	2.3%
		10th	4	7	2.2%	2.3%
		11th	75	124	41.0%	41.3%
		Total	83	138	45.4%	46.0%
	x	Total	83	138	45.4%	46.0%
		11th	22	31	12.0%	10.3%

Table 35 (cont'd)

Descriptive Statistics for Students who Stated True by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	11	22	6.0%	7.3%
		10th	10	14	5.5%	4.7%
	Total	11th	162	263	88.5%	87.7%
		x	0	1	0.4%	0.3%
		Total	183	301	100.0%	100.0%

As seen in Table 35 above, 78 out of 131(59.54%) male students from 9th, 10th, and 11th grade who participated in the test said that the statement is true. While 83 out of 138 (60.14%) female students said that the statement is true. The ratio of male and female students who said true was almost equal. Half of the 9th grade students who participated in the test expressed that the statement is true, while 10 out of 14 that is the majority of10th grade students who participated in the test said that the statement is true. When only 11th graders were considered, then 162 (61.59%) out of 263 of them said that the statement is true.

Category: False

Descriptive statistics for students who said false for the statement by gender and grade.

Table 36

Descriptive Statistics for Students who Stated False by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	2	15	4.9%	5.0%
	M	10th	0	7	0.0%	2.3%
		11th	23	108	56.1%	36.0%

Table 36 (cont'd)

Descriptive Statistics for Students who Stated False by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
	M	x	0	1	0.0%	0.3%
		Total	25	131	61.0%	43.7%
	F	9th	1	7	2.4%	2.3%
		10th	0	7	0.0%	2.3%
		11th	12	124	29.3%	41.3%
		Total	13	138	31.7%	46.0%
False	x	11th	3	31	7.3%	10.3%
		Total	3	31	7.3%	10.3%
	Total	9th	3	22	7.3%	7.3%
		10th	0	14	0.0%	4.7%
		11th	38	263	92.7%	87.7%
		x	0	1	0.0%	0.3%
		Total	41	300	100.0%	100.0%

As seen in Table 36 above, 41 out of 300 students (13.66%) believed that the statement was false. A slightly higher ratio of male students, that is 25 out of versus 13 out of 138 female students agreed that the statement was false. The number of male students who said false is higher than that of female students. While 19% of the male students answered no, only about 10% of the female students answered no.

Category: No Answer

Table 37 shows the descriptive statistics for students who did not answer the question by gender and grade.

Table 37

Descriptive Statistics for Students who did not Answer the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
No answer	M	9th	6	15	7.9%	5.0%
		10th	1	7	1.3%	2.3%
		11th	20	108	26.3%	36.0%
		x	1	1	1.3%	0.3%
		Total	28	131	36.8%	43.7%
	F	9th	2	7	2.6%	2.3%
		10th	3	7	3.9%	2.3%
		11th	37	124	48.7%	41.3%
		Total	42	138	55.3%	46.0%
	x	11th	6	31	7.9%	10.3%
		Total	6	31	7.9%	10.3%
	Total	9th	8	22	10.5%	7.3%
		10th	4	14	5.3%	4.7%
		11th	63	263	82.9%	87.7%
		x	1	1	1.3%	0.3%
		Total	76	300	100.0%	100.0%

As seen in Table 37 above, about one fourth, that is 76 out of 300 students (25.33%) did not answer the question. When gender was considered than we again observe that female students were a bit more conservative and reluctant in answering the question. 28 out of 131 male students versus 42 of 138 female students failed to answer the question.

Answers and Results for Question Number 7 Part A

The seventh question was "It is said that earth is an inertial frame for most terrestrial experiments, but a non-inertial frame for astronomical observations. How can the same frame of reference be inertial for one purpose and non-inertial for another? Explain. Statistical information on this question is given in Table 38 to 41.

Category: Relativity

Table 38 shows the descriptive statistics results on the category of question number 7 labeled as relativity by gender and grade.

Table 38

Descriptive Statistics for Students who Stated Relativity by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Relativity	M	9th	0	15	0.0%	5.0%
		10th	1	7	1.6%	2.3%
		11th	27	108	42.9%	36.1%
		x	0	1	0.0%	0.3%
		Total	28	131	44.4%	43.8%
	F	9th	0	7	0.0%	2.3%
		10th	4	7	6.3%	2.3%
		11th	27	125	42.9%	41.8%
		Total	31	139	49.2%	46.5%
	x	11th	4	29	6.3%	9.7%
		Total	4	29	6.3%	9.7%
	Total	9th	0	22	0.0%	7.4%
		10th	5	14	7.9%	4.7%
		11th	58	262	92.1%	87.6%
		x	0	1	0.0%	0.3%
		Total	63	299	100.0%	100.0%

As seen in Table 38 above, 63 out of 300 (21.07%) of all the students who participated in the study used the concept of relativity. While none of the 9th grade students used the concept of relativity, only 4 out of 14 10th grade students used the concept of relativity. 58 out of 262 11th grade students used the concept of relativity. A slightly higher ratio when considered with the total student body. This is not to surprising since the students are taught the motion of objects at constant velocity in a dynamic environment according to different observation perspectives within the scope of the relative motion subject in 11th grade curriculum. The number of male and female students who used the concept of relativity was almost equal.

Category: Because of Gravity

Table 39 shows the descriptive statistics results on the category of question number 7 labeled because of gravitation by gender and grade.

Table 39

Descriptive Statistics for Students who Stated Because of Gravitation by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
Because of Gravitation	M	9th	0	15	0.0%	5.0%
		10th	0	7	0.0%	2.3%
		11th	3	108	27.3%	36.1%
		x	0	1	0.0%	0.3%
		Total	3	131	27.3%	43.8%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	5	125	45.5%	41.8%
		Total	5	139	45.5%	46.5%
	x	11th	3	29	27.3%	9.7%
		Total	3	29	27.3%	9.7%

Table 39 (cont'd)

Descriptive Statistics for Students who Stated Because of Gravitation by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	0	22	0.0%	7.4%
		10th	0	14	0.0%	4.7%
	Total	11th	11	262	100.0%	87.6%
		x	0	1	0.0%	0.3%
		Total	11	299	100.0%	100.0%

As seen in Table 39 above, only 11 out of 299 students provided answer because of gravity as a rational for explaining the reason for choosing the inertial versus non- inertial reference frame preference. It is not a big surprise that none of the 9th and 10th grade students used the concept of gravity most likely because of the curriculum. When considering gender, we observe a similar finding that is the number of male and female students who used the concept of gravity is almost equal.

Category: Different Environment

Descriptive statistics for students who used the concept different environment by gender and grade.

Table 40

Descriptive Statistics for Students who Stated Because of Gravitation by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
		9th	0	15	0.0%	5.0%
	M	10th	0	15	0.0%	5.0%
		11th	3	108	27.3%	36.1%

Table 40 (cont'd)

Descriptive Statistics for Students who Stated Because of Gravitation by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
	M	x	0	1	0.0%	0.3%
		Total	4	131	40.0%	43.8%
	F	9th	0	7	0.0%	2.3%
		10th	0	7	0.0%	2.3%
		11th	6	125	60.0%	41.8%
		Total	6	139	60.0%	46.5%
Different environment	x	11th	0	29	0.0%	9.7%
		Total	0	29	0.0%	9.7%
	Total	9th	0	22	0.0%	7.4%
		10th	0	14	0.0%	4.7%
		11th	10	262	100.0%	87.6%
		x	0	1	0.0%	0.3%
		Total	10	299	100.0%	100.0%

As seen in Table 40 above, only 10 out of 299 students provided answer because of different environments as a rational for explaining the reason for choosing the inertial versus non- inertial reference frame preference. Most likely students perceive that the earth and space are different environments. Only 11th grade students used the different environment perspective, 9th and 10th grade students did not give such an explanation when answering the question. Different environment explanation was used almost equally among male and female students.

Category: No Answer

Table 41 shows the descriptive statistics results on the category of question number 7 labeled described the motion of the ball as forward from the point of view of an observer inside the train by gender and grade.

Table 41

Descriptive Statistics for Students who did not Answer the Question by Gender and Grade Level

Category	Gender	Grade	Sum	N	Total Sum %	Total N%
No answer	M	9th	14	15	6.8%	5.0%
		10th	6	7	2.9%	2.3%
		11th	71	108	34.6%	36.1%
		x	1	1	0.5%	0.3%
		Total	92	131	44.9%	43.8%
	F	9th	6	7	2.9%	2.3%
		10th	3	7	1.5%	2.3%
		11th	83	125	40.5%	41.8%
		Total	92	139	44.9%	46.5%
	x	11th	21	29	10.2%	9.7%
		Total	21	29	10.2%	9.7%
	Total	9th	20	22	9.8%	7.4%
		10th	9	14	4.4%	4.7%
		11th	175	262	85.4%	87.6%
		x	1	1	0.5%	0.3%
		Total	205	299	100.0%	100.0%

As seen in Table 41 above, 205 out of 299 (68.56%) student had no answer. This was by far one of the hardest questions in this test. 98 out of 131 male students versus 92 of 139 female students, did not answer the question. The number of male students who did not answer the question is slightly higher than that of female students. Interestingly, 70% of the male students did not answer the question, while 66% of the female students did not answer the question. Usually female students were more reluctant. But the margin was not significant, so we can conclude that the ratio was approximately the same.

Result for Part B

Part B of the test consisted to 12 forced multiple-choice type of questions. This section reported on the item analyses conducted using classical psychometric theory. The following information were reported on the results of analyses, item concepts such as item difficulty, item discrimination and reliability values were listed. It continued with a detailed report on each item response per distractor. The following forced choices were provided for each statement:

a. The statement is definitely true.
b. Not sure, but the statement might possibly be true.
c. Not sure, but the statement appears to be wrong.
d. The statement is definitely untrue (or) it does not make sense

Table 42

Item Difficulty and Discrimination Values

Item Number	NA	Item Difficulty	Item Discrimination	α if deleted
1	10.04 %	0.062*	0.139	0.172
2	10.04 %	0.112*	0.308	0.707
3	9.65 %	0.186*	0.355	0.591
4	10.04 %	0.136*	0.366	0.693
5	11.20 %	0.155*	0.389	0.732
6	10.42 %	0.093*	-0.034	0.146
7	10.81 %	0.120*	0.081	0.171

Table 42 (cont'd)

Item Difficulty and Discrimination Values

Item Number	NA	Item Difficulty	Item Discrimination	α if deleted
8	10.42 %	0.143*	0.139	0.353
9	11.97 %	0.039*	0.132	0.386
10	13.51 %	0.070*	0.248	0.366
11	11.58 %	0.236	0.265	0.251
12	11.58 %	0.252	0.161	0.493

Cronbach's α=0.53 NA: No Answer Index *: difficult questions

Table 42 is a summary of the item analysis. By definition item difficulty value ranges from zero to one. The closer the item difficulty value is to zero the harder the item is, the closer the value is to one, the easier the item is. The item difficulty value essentially reports the ratio of correct answers on an item. The test in general is a difficult one! The most difficult question on the test is question number 9 (p= .039), followed by question number 1 (p= .062) and 10 (p= .070). Despite the difficult nature of the test, we observed from the "item discrimination" column that the test in general was able to differentiate between the upper and lower groups. Item number 6 has a minus discrimination index value. Particularly this item needs attention. The Cronbach alpha value is somewhat low. For achievement type of tests, a value of 0.6 and higher are desired.

As reported earlier, part B was composed of two main base statements. Based statement 1 had seven questions and base statement number 2 had three questions each with four forced distractors. Base statement 1 was combined with a picture of the turn table and the two coins. The was no figure provided for base statement 2 (see appendix A). The main two base statements were as follows:

Part B: Base statement 1 A turntable kept on a platform rotates clockwise with a constant angular speed. Coin 1 rests on the rotating turntable, while coin 2 rests on the platform.

Part B: Base statement 2: A stone is tied to a string and rotated uniformly in a horizontal circle.

Below shown in Table 43 is a detailed breakdown of student answers for each distractor for each questions sorted by grouping.

In order to make some grounded conclusions, grouping the answers for both statement bases seems to be an appropriate way to proceed. Thus, the following four groups were formed. These were:

1 In a lab/ground frame versus no frame/relativity

2 Rotating versus steady objects

3 Rotating frame

4 Newton’s law

Table 43

Response Ratio for Each Distractor by Grouping

Item	Gr	NA	A	B	C	D
1a In the lab frame, there is a centrifugal force on the stationary coin 2	1	0.101	0.388	0.372	0.078	0.062
1c No matter which frame, there is a centrifugal force on coin 1 but not on coin 2.	1	0.097	0.205	0.275	0.236	0.186
1f In the lab frame there is no centrifugal force on either coin 1 or coin 2.	1	0.105	0.093	0.155	0.236	0.411
2a. In the lab frame, there is a centrifugal force on the rotating stone	1	0.136	0.322	0.368	0.105	0.070
1b In the rotating turntable's frame, there is a centrifugal force on coin 1 but not on coin 2.	2	0.101	0.295	0.318	0.174	0.112
1d There is no centrifugal force on coin 2 in either frame, because coin 2 is outside the turntable.	2	0.101	0.275	0.295	0.194	0.136
1e There is no centrifugal force on coin 2 in either frame, because coin 2 is in fact stationary.	2	0.112	0.256	0.310	0.167	0.155
1g In the rotating turntable's frame, coin 2, which appears to rotate (anticlockwise) has a centrifugal force, but coin 1, which is stationary with respect to the frame, does not have a centrifugal force.	3	0.109	0.120	0.287	0.233	0.252
1h In the rotating turntable's frame, both coins 1 and 2 have centrifugal force.	3	0.105	0.302	0.322	0.128	0.143
1i The centrifugal force on coin 2 in the rotating frame is only apparent (i.e. it really does not exist), because coin 2 is actually at rest.	3	0.120	0.550	0.248	0.043	0.039
2b. The centripetal force (due to tension in the string) and the centrifugal force on the stone are equal and opposite by Newton' third law.	4	0.116	0.236	0.376	0.163	0.109
2c. In the rotating stone's frame, the centrifugal force on the stone is balanced by the force due to tension.	4	0.116	0.132	0.217	0.283	0.252

Note. See Appendix C for histogram graphs of each item

Figure 3

Cumulative Values For Choice 'a and b' and 'c and d'

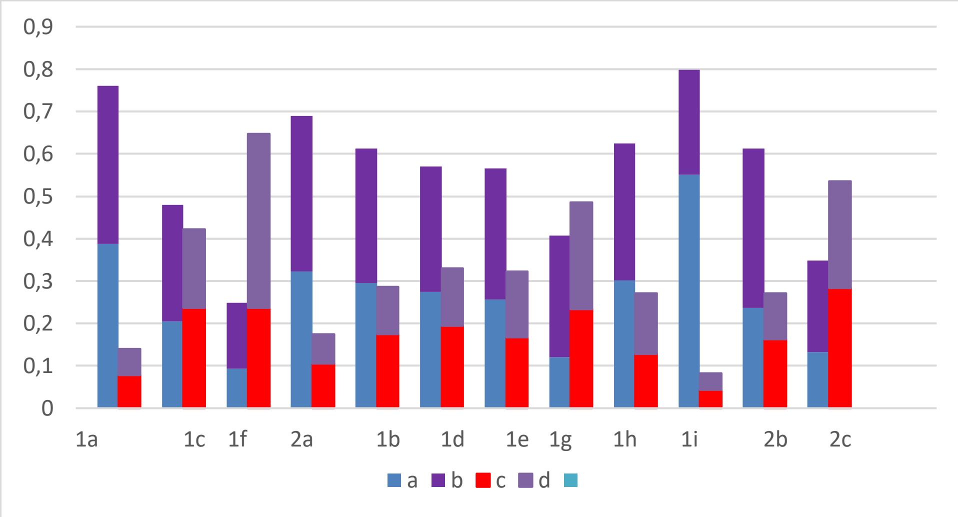


Figure 3 is a graph representing the cumulative values for choice "a and b" and "c and d". The x-axis was sorted based on the grouping values shown in Table 43. So group 1 (1a,1c,1f and 2a), group 2 (1b, 1d,1e and 1g), group 3 (1g,1h, and 1i) and group 4 (2b and 2c).

For the first group, that is when the students were force to choose or identify between "a lab/ground frame versus no frame" question 1f showed a significantly drop in certainty and an increased ratio in uncertainty. This response most likely did result because of the apparent contradictory notion of 1c and 1f.

For group 2 we observed a constant pattern. This result was consistent with PER. Since naïve student thinking usually associates an object's motion to its attribute. For example, students tend to believe that motion is natural to living things such as animals. This same approach seems to hold true for reference frames as well. The question has asked to make a choice based on the object's attribute "Rotating versus steady" objects.

For group 3 we have observed a similar behavior as group 2. Again students tend to use motion, this time the motion of the reference frame as an attribute. The slight drop of question 1g might be account most likely for its length and somewhat complex wording.

For group 4 we observed a strong believe that a rotating object exerts a counter force. Students clearly confuse the concept of inertia versus daily life experience. This comes to no surprise since this type of misconception is well reported and know in the physics education community. There is a drop for 2c, one plausible explanation could be that students perceived this question to be a contradicting one to 2b.

Chapter Summary

Chapter 4 provided a detailed analysis on the data collected from 9^{th}, 10^{th} and 11^{th} grade high-school students. A total of about 300 students participated in the study, with the majority of 11^{th} grade students. The female male ratio, resembled approximately the same Turkish gender distribution ratio, there were slightly more female students present. But overall gender distribution could be accepted as balanced.

A test that was translated into Turkish was used. The test was composed of two parts; A and B. Part A had 7 open-ended questions. While part B consisted of forced 4 distractors multiple-choice type of 12 questions.

The first section started by outlining the scoring and category establishment procedure. As a result of the procedure, a total of 40 categories were established. The categories were driven on student written responses. A procedure known as OLAP Cube was utilized after the establishment of the categories. All descriptive data for each of the 40 categories was listed and briefly explained. Important anomalies' and points were explained as well. The tables were sorted from student highest to lowest response rate.

The second section was about the results obtained from part B of the test. Part B was a forced multiple choice type test. The test had two main or base statements which 12 questions were formed. The analysis show that the majority of the students, independent from gender, chose their answer based on object and reference frame attribute, such in-motion, at rest or rotation. An overall conclusion was that the test was difficult for students. Moreover, 9th and 10th grade students had experienced the most difficulty. Most often they failed to answer the questions, especially the open-ended once.

CHAPTER 5: CONCLUSION

Introduction

This study was carried out to determine students' understanding about inertial and non-inertial reference frames. 9th, 10th and 11th-grade high-school students who were enrolled in a physics course participated in the study. Understandings of all students initially, then grade and gender by were analyzed.

As mentioned in chapter 3 and 4, the test was composed of two parts - A and B. The questions include questions that measures how well students did internalize and comprehend non-inertial and inertial reference frames and Newton's laws of motion. Part A of the test consisted of 7 open-ended questions. Part B consisted of 12 forced multiple-choice type questions each with four distractors.

Discussion Part A

The first question of part A of the test asked students to state in which direction they felt they were being pushed on a rotating carousel. The question received one of the highest responses and a detailed analysis was presented in tables 2-7. Students answered this question with some sort of a concept involving direction either a rotational or transversal description of the push they felt (e.g., I feel being pushed-out, I force myself inward and so on). The reason for such a high probably lies in the “experience” of centrifugal force. This could stem from child ground marry-go-round and/or in sitting in a car or bus negotiating road curves. This shows that most physics student did not synthesize or internalize the formal school knowledge with their daily life experiences. Because personal experience of the students is an impediment in front of the scientific knowledge (Alwan, 2010). This fact has been reported over and over in PER literature. The second highest common concept was inertia.

Here it should be noted that 9th and 10th grade students failed provide any answer. The answers were from 11th grade students whom had clearly a more advanced understanding. Inertia is defined as is the resistance of mass to any change in its velocity. So students that had a more advanced understanding of the relationship between speed and change of direction were more likely to use the concepts related to Newton's 1st and 2nd law. However, as stated in chapter 4 9th and 10th-grade students did not use the inertia concept at all while they answer the question. They actually learn the concept of inertia and Newton's laws of motion which were included in the subjects of force and motion in the 9th grade curriculum. But to be frank, even at the university freshmen level, inertial and non-inertial reference frames are mentioned very briefly at a rudimentary level. It is so clear that students have difficulty even explaining the topics which discussed. Most of the students have difficulty with ideas that include the concept of frame of reference (Scherr et al., 2001). One reason why the students in 9th and 10th-grade never use this concept, but while they use in the 11th-grade could be that they study Newton's laws of motion again in the unit of mechanics at the beginning of the curriculum or school year.

As physics teachers we tend to emphasize the importance between an objects rotating path and its relation to centripetal and centrifugal forces. As stated at the beginning of the paragraph, while most of the students used some sort a direction descriptor, only 26 mentioned “centrifugal force/merkez kaç”. This is most likely a result of the instruction. The results seem clearly that most students possessed the notion of centrifugal force but refrained themselves using the term explicitly.

This shows that they could not synthesize the formal school knowledge that they have learned with their daily life experiences. This fact has been reported over and over in PER literature. While 90.78% of the female students gave information about which direction they were pushed, 80.90% of the male students gave this information.

Question two involved a scenario experienced perhaps daily by most of us, including high school students (table 8 -12). In Turkey, a significant number of students use school busses on a daily basis when commuting from home to schools and vice versa. Moreover, one could easily argue that the “force” felt from a decelerating bus is easier to be explained. Not surprisingly, that this question too received one of the highest responses. The concept “backward” and “inertia” were the two common answers used by the students to describe what they felt. Clearly, students tended to choose daily life experiences prior school knowledge when confronted with experiential common daily life situations such as the seat-bus relationship. However, unlike the previous question, this question puts the students “into” the reference frame. When comparing question number 1 and 2, we clearly see that at this point “the feeling criterion” (anthropomorphic) is being used by the students. The other two common answers, the push of the bus seat and the instantaneous “forward” torso motion could be interpreted in the same manner. At this point students have not explicitly made any concrete reference to inertial or non-inertial reference frames.

The third question is another daily life example. Students answers were listed trough table 13-20. We are told from early years that the earth revolves around its own axis and that this is the cause of day and night. But in reality the axial revolution, earth’s tilt and circular motion around the sun is very complex in nature.

This is not an easy straight forward concept to be readily learned. First off, this question was one of the hardest two questions (the other one was question 5 slightly more difficult). The majority of the students can not answer the question. When analyzing the ones that did, we clearly see that the students made a reference to the “earth”. That is, even though a small minority students used the first time reference frame. Earth is usually perceived as a natural inertial reference frame. Size obviously was also referenced. The sun’s mass size when compared to the earth’s is obviously why larger. Students’ are well versed and must have seen many animation showing the smaller mass earth revolving around the massive sun. This most likely explains the reason of the 83 students (table 14,15 & 16) that chose these particular concepts.

For question four (table 21-25), like question 3 probed the student to imagine the scenario as an outside observer. While in question 3 the students put themselves “on the earth”, in question 4 they want be able to use the same strategy because the question explicitly describes two individuals a child on the marry-go-around, and a man sitting still on the ground. This is the first time students are confronted with the pseudo force-centrifugal. The majority of the student believed that there was a centrifugal force on the rotating child. This result is in agreement with the answer received in question 1. Once more there is an indicating that high-school physics students tend to associate centrifugal forces acting on rotating objects. When the man was to be explained, we have observed a split in responses. The first group of students believed that there was no centrifugal force on the man, just because he was stationary. This explanation is in agreement with the attribute or criterion of motion as an attribute to the reference frame. Simply speaking, since the man is not rotating then there is no centrifugal force acting up on him.

A similar phenomenon well known about the book laying on a table. A common misconception is that students then to forget the normal force acting upon the table or an object at rest does not experience any force. The second group accounted for a centrifugal force, the reason mostly is the notion of relativity. In the upcoming questions we created a concept/category of relativity. So most likely students believed that the centrifugal force was a relative attribute. Although question 4 seemed to be an easy question as far as the difficulty index was concerned, it was a question which yielded mixed balanced results, indicating that the students generated concepts were all equal weight.

Question 5 (table 26 to 34) generated the most categories. The reason was that student had to comment for two scenarios, one as an observer inside the train wagon and two, as an observer outside the wagon on a stationary station. This question asked students to comment on a rolling ball inside a train from two different observation reference frames. One inside the slowing down train and the other one from the outside at a stationary railway station. The majority of the students stated that the ball would roll forward when the train starts to slow down as observed inside of the train wagon. Almost the same ratio of students claimed to see the same phenomenon as an outside observer. This second misconception is well documented in the literature. A similar question exists on the force concept inventory that askes student to determine the trajectory of a falling ball from a horizontally flying airplane. The other two categories were split equally and involved an explanation of backward movement of the ball. It seems that in both cases the student tends to "attached" the frame of reference to the train wagon.

Although the questions were open-ended, question 6 (table 35-37) constraint students answer to "true" or "false" options so in this case, question 6 was slightly different than the other questions. The majority of the students agreed with the statement. The student used Newton's third law to justify their answer –action-reaction pair forces. Since the stone was in "balance" so the forces had to be equal and opposite! The students neglected again formal school knowledge or uniform circular motion. This type of misconception is well supported in the literature. Student tend to explain that a rotating object will fly directly "outward" if the string is cut and the object comes lose. The rational provided is that the "centrifugal" force will make it fly outward.

The last question, that is question number 7 was the most difficult one (table 38 – 40). 205 students did not answer the question. One plausible reason is that the question was unfamiliar o the student body and too conceptual. The question, clearly is not an experiential one such as the first few questions were. Question 7 is more abstract in nature. Considering the unfamiliarity of the topic, the results come to as no surprise.

Discussion Part B

Questions provided in part B were more direct. The students had to choose among four distractors. The distractors were as follows:

a. The statement is definitely true.
b. Not sure, but the statement might possibly be true.
c. Not sure, but the statement appears to be wrong.
d. The statement is definitely untrue (or) it does not make sense

As one can see, distractor a and b do complement each other, and should as such analyzed. The same logic holds true for distractors c and d. C and d too should be analyzed together. Hence Figure 3 displaying the cumulative bar charts was created and depicted in Chapter 4. Part B provides further evidence about students understanding of inertial and non-inertial reference frames. Clearly the topic is a difficult one as the results of the item analysis showed. Student used four type of common rational that were apparent while answering the questions.

In a Lab/Ground Frame Versus No Frame/Relativity

When there was a ground or some other source of reference frame such as the train wagon, stationery man and so on, the natural tendency was to employ those as a frame of reference for linear type of motions, including acceleration and deceleration.

Rotating Versus Steady Objects

Student tended to apply centrifugal forces to rotation objects. Essentially, kinematics of the object, in this case rotation was an attribute used by students to determine the mechanics. This is similar to motion and force misconceptions in Newtonian mechanics. Within of the question shown in histogram graph, there seemed to be a high degree of internal consistence especially the ratio of "a" distractors (1d, 1e and 1g).

Rotating Frame

Students seemed to have two different approaches when dealing with rotating frames. The first one, which is the more advanced understanding is to use relative motion idea. For example, 1g motion is relative. Or in part A, the sun and earth motion are also perceived reality, albeit by a small amount of students. The second group does fail to acknowledge rotating frames altogether when encountering rotating frames and reverts back to the kinematic view point.

Newton's Law

When rotating objects are tied or constrained by "real" objects such as a string, then students tend to use Newton's law of motion. This is true for a rotating stone in Part A and consistent with a follow up question in Part B.

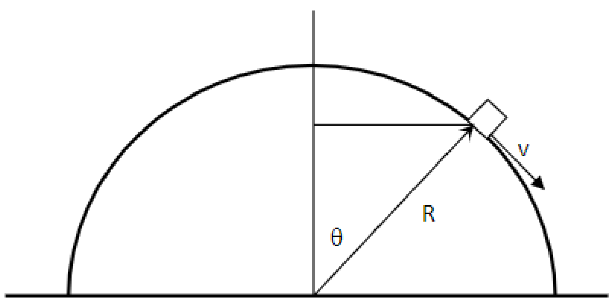
General Conclusion

We have established that when students decided the inertial nature of reference frame that they use some sort of simplistic prior criterion. For example, if the students believe to be "within" or "with" the frame of reference, like being in the train wagon or on earth then the reference frame is inertial. If the students perceive to be outside, and "see" an acceleration (deceleration) or rotation than the reference frame is non-inertial. For example, a common physics question which involves the fundamental understanding on non-inertial reference frame. Figure 4 shows the question is well known by the PER community and labeled a difficult. The difficult part is the ability to correctly applied frame of reference and not the mathematics.

Figure 4

Question About Particle Sliding on Semi-Circular Dome

5. Frictionless Hemisphere. Consider a frictionless hemispherical dome. A small object is placed at the top, and gently nudged, so that it slides down the side. As the object slides, it picks-up speed, until it finally loses contact with the dome. *Calculate the angle* at which the object loses contact. (**Hint**: The *height* of the object at any given angle θ is R*cos(θ). The difference in heights, R – R*cos(θ), represents a *difference in potential energy*. (a) Use ΔPE = ΔKE to find the velocity, v, for any θ. (b) At the fly-off point, the normal force goes to zero, leaving the normal component of gravity, g*cos(θ), equal to v^2/r. See the figure below.)



Further, student's kinematic attributes to objects is another common tool to decide the type of reference frame. An objects rotation grand non-inertial reference frame, whereas "at rest" or stationary equates to inertial reference frames. Size and mass of an object too play a part in the same way of determining the nature of reference frame decision. Especially when two or more objects have to be compared. Some students, however, employ relativism. As the example of the man on the ground and child rotating on the carousel, or the coin on the rotating plate versus the coin stationary on the ground. It seemed that the taught relativity principle leads to an understanding that all frames of references can be considered as equivalent, thereby abounding the idea of inertial and non-inertial reference frames. This study indicated that students have inconsistent ideas and are confused when dealing with inertial and non-inertial reference frames.

Implications for Practice and Further Research

The concept and correct determination of inertial and non-inertial reference is an important topic in physics education. Moreover, the topic is difficult to teach and understand. High school students are already overwhelmed with many "new" concepts introduced in introductory mechanics, such as vectors, kinematics, Newton's laws of motion, energy, circular motion momentum and so on. Most of these topics make use of reference frames. But quite often they are implied, and not much time is devoted in PER classes explicitly to the procedure of determining the reference frame.

As this study clearly showed, the 9^{th} and 10^{th} grade students have a very limited understanding of inertial and non-inertial reference frames. They were reluctant to answer the questions. Of course the student numbers were not very high, especially when compared with the 11^{th} grade student numbers. But it seems that the same conclusion for the 9th and 10th graders could be drawn even if the number would have been much larger. So, the first implication would be on a more detailed research involving 9th and 10th graders. Perhaps a good way would be to develop a study with a few numbers of student to probe orally for their understanding. Written test seems to not created the desired amount of data from these two group of student population.

The study data were collected from high school students only. One natural expansion of this research would be to conduct a research that would involve physics teacher. Both assessing teachers understanding of inertial and non-inertial reference frames and probing teachers own perception and opinions about teaching this topic. These type of study could help determining, where student difficulties arise, and also if teachers partly are responsible for some of the misconceptions encountered. Relatively seems to be another topic confused by students. A comparing possible relationship between student's understanding special relativity and reference frames might help to even further unveil student true understanding of the complex concepts of inertial and non-inertial reference frames.

Limitations

All the answers provided by the students were considered to be true and to their fullest possible potential.

It was assumed that al the written material and figures were understood by the students in the same way and answered under the same circumstantial condition.

It was assumed that all students were exposed to the same national physics curriculum.

The sample was limited to schools in Çankaya district of Ankara, Turkey

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APPENDICES

Appendix A

Original of Data Collection Instrument

Part A: The Free Response Test

1 Image yourself sitting steady in a rotating merry-go-round. In which direction do you feel yourself being pushed? Why? Then what prevents our motion in that direction?

2 Imagine yourself sitting in an accelerating bus, facing forwards. In which direction do your feel yourself being pushed? Why? Then what prevents your motion in that direction?

3 Motion, it is said, is relative. For example, on the earth's frame of reference, the sun moves across the sky each day from east to West; while in the sun's frame of reference the earth rotates about its axis. Yet we insist that the motion of the sun around the earth is apparent, and it is the earth that actually rotates. What is the basis for this preference? (Please ignore the presence of other planets in the solar system.)

4 A child is sitting in a rotating merry-go-round and a man in standing on the ground. In the ground's frame of reference, is there a centrifugal force on the child? In the child's frame of reference, is there a centrifugal force on the man? Explain.

5 A train is moving uniformly. A ball rests on the floor of the train. If the train slows down suddenly, describe and explain the motion of the ball both from the point of view of a train observer and a ground observer. Ignore friction.

6 A stone is tied to a string and rotated uniformly in a horizontal circle. Is the following statement true? 'The tension in the string and the centrifugal force

on the stone are equal and opposite, and therefore keep the stone in equilibrium.' Explain your answer.

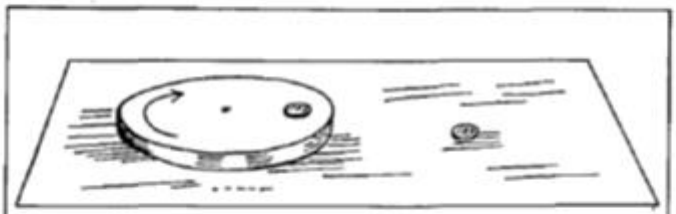
7 It is said that the earth is an inertial frame for most terrestrial experiment, but a non-inertial frame for astronomical observations. How can the same frame of reference be inertial for one purpose and non-inertial for one purpose and non-inertial for another? Explain.

Part B: The Forced Option Test and Results

In the various problem situations below, a series of statements are given. Some of these statements are followed by the options 'a, b, c, d'. Please select one of the four options by circling it, using the following key

e. The statement is definitely true.
f. Not sure, but the statement might possibly be true.
g. Not sure, but the statement appears to be wrong.
h. The statement is definitely untrue (or) it does not make sense.

Consider the statements only in the given sequence. Do not go back to any question that you have already read.



Q.1

1 A turntable kept on a platform rotates clockwise with a constant angular speed. Coin 1 rests on the rotating turntable, while coin 2 rests on the platform. (see Figure 1)

1a. In the lab frame, there is a centrifugal force on the stationary coin 2.

1b. In the rotating turntable's frame, there is a centrifugal force on coin 1 but not on coin 2.

1c. No matter which frame, there is a centrifugal force on coin 1 but not on coin 2.

1d. There is no centrifugal force on coin 2 in either frame, because coin 2 is outside the turntable.

1e. There is no centrifugal force on coin 2 either frame, because coin 2 is in fact stationary.

1f. In the lab frame there is no centrifugal force on either coin 1 or coin 2.

1g. In the rotating turntable's frame, coin 2, which appears to rotate (anticlockwise) has a centrifugal force, but coin 1, which is stationary with respect to the frame, does not have a centrifugal force.

1h. In the rotating turntable's frame, both coins 1 and 2 have centrifugal force.

1i. The centrifugal force on coin 2 in the rotating frame is only apparent (i.e. it really does not exist), because coin 2 is actually at rest.

I.2 A stone is tied to a string and rotated uniformly in a horizontal circle.

2a. In the lab frame, there is a centrifugal force on the rotating stone.

2b. The centripetal force (due to tension in the string) and the centrifugal force on the stone are equal and opposite by Newton' third law.

2c. In the rotating stone's frame, the centrifugal force on the stone is balanced by the force due to tension.

2d. Centrifugal force cannot balance tension because centrifugal force is a fictitious force; it cannot balance a real force like tension.

Appendix B

Turkish Version of Data Collection Instrument

Kısım 1: Açık Uçlu Sorular Anketi

Kendinizi dönen bir atlıkarıncanın üzerinde sabit bir şekilde otururken hayal edin. Hangi yöne itildiğinizi hissediyorsunuz? Neden? O zaman bu yönde hareketimizi engelleyen şey nedir?

Kendinizi hızlanan bir araba içinde hayal edin. Hangi yöne hissediyorsunuz? Neden? O zaman bu yönde hareketimizi engelleyen şey nedir?

Hareketin göreceli olduğu söylenir. Örneğin; Dünya'nın referans çerçevesinde, Güneş her gün gökyüzü boyunca doğudan batıya doğru hareket eder; Güneş'in hareketinin referans çerçevesinde ise Dünya kendi ekseni etrafında döner. Bunarağmen, Güneş'in Dünya çevresindeki hareketinin sanal olduğu konusunda ısrarediyoruz, ve aslında dönen Dünya'dır. Bu tercihin temeli nedir? (Güneş sistemindeki diğer gezegenlerin varlığını gözardı ediniz.)

Bir çocuk dönen bir atlıkarıncanın üzerinde oturuyor ve babası duran platformunüzerinde ayakta duruyor. Duran platformun referans çerçevesinde, çocuğun üzerinde bir merkezkaç kuvveti var mı? Çocuğun referans çerçevesinde, adamın üzerinde bir merkezkaç kuvveti var mı? Açıklayınız.

Zemininde top duran bir tren düzgün doğrusal hareket yapıyor. Trenin ani şekildeyavaşladığı durumda, topun hareketini tren içinde ve tren dışında sabit duran birşekilde duran gözlemcilerin görüş açısından tanımlayınız ve açıklayınız. (Sürtünmeyi ihmal ediniz).

İpe bağlanmış bir taş yatay bir düzlemde düzgün dairesel hareket yapıyor. "İptekigerilme ve taş üzerindeki merkezkaç kuvveti eşit büyüklükte ve zıt yöndedir bu nedenle taşı dengede tutmaktadır." önergesi doğru mudur? Açıklayınız.

Dünya’nın, çoğu karasal deneyler için bir eylemsiz çerçeve olduğu söylenir, amaastronomik gözlemler için eylemsiz olmayan çerçevedir. Nasıl aynı referans çerçevesi bir amaç için eylemsiz olabiliyorken diğer bir amaç için olmayabiliyor?

Kısım 2: Çoktan Seçmeli Sorular Anketi

Aşağıdaki çeşitli problem durumlarında, bir dizi ifade verildi. Bu ifadelerin bazılarını ‘a,b,c,d’ seçenekleri izlemektedir. Daire içine alarak bu ifadelerden birini seçiniz, aşağıdaki anahtarı kullanarak.

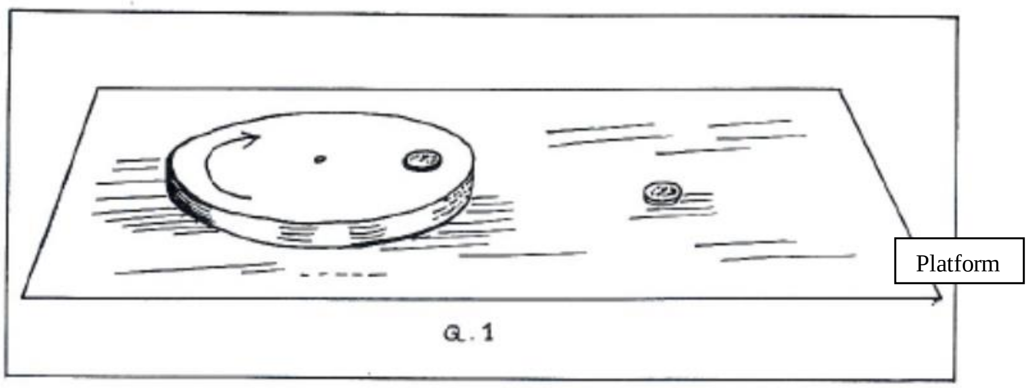
a: İfade kesinlikle doğru.

b: Emin değilim, ama ifade belki doğru olabilir.

c: Emin değilim, ama ifade yanlış gibi görünüyor.

d: İfade kesinlikle yanlış (ya da) mantıklı değil.

İfadeleri sadece verilen sırayla düşünün. Daha önce okumuş olduğunuz herhangi bir soruya geri dönmeyin.



Şekil 1.

A. Laboratuvar ortamında bir döner tabla, saat yönünde sabit bir açısal hız ile dönen bir masa üzerinde tutuluyor. Madeni para 2 masa üzerinde dururken, madeni para 1 dönen döner tabla üzerinde duruyor.

I. Bir Laboratuvar ortamında platform üzerinde bulunan bir gözlemci tarafından, dönen madeni para 1'in üzerinde merkezkaç kuvveti vardır ama duran madeni para 2'nin üzerinde merkezkaç kuvveti yoktur.

II. Dönmekte olan döner tabla çerçevesine göre , madeni para 1'in üzerinde merkezkaç kuvveti vardır ama madeni para 2'nin üzerinde merkezkaç kuvveti yoktur.

III. Hangi gözlem çerçevesinde olursa olsun, madeni para 1'in üzerinde merkezkaç kuvveti vardır ama madeni para 2'nin üzerinde merkezkaç kuvveti yoktur.

IV. Her iki gözlem çerçevesinde de madeni para 2'nin üzerinde merkezkaç kuvveti yoktur, çünkü madeni para 2 döner tablanın dışındadır.

V. Her iki gözlem çerçevesinde de madeni para 2'nin üzerinde merkezkaç kuvveti yoktur, çünkü gerçekte madeni para 2 masa üzerinde sabit durmaktadır.

VI. Laboratuvar gözlem çerçevesi içinde madeni para 1 ve madeni para 2'nin üzerinde merkezkaç kuvveti yoktur

VII. Dönmekte olan döner tablanın gözlem çerçevesi içinde, madeni para 1 ve madeni para 2'ye merkezkaç kuvveti vardır.

VIII. Dönmekte olan gözlem çerçevesi içinde madeni para 2'nin üzerindeki merkezkaç kuvveti sadece sanaldır (gerçekte mevcut değil.), çünkü madeni para 2 aslında sabit durmaktadır.

B. Bir taş bir ipe bağlanmış ve yatay bir daire içinde düzgün bir şekilde döndürülüyor.

I. Laboratuvar gözlem çerçevesine göre, dönen taşın üzerine merkezkaç kuvveti etki eder.

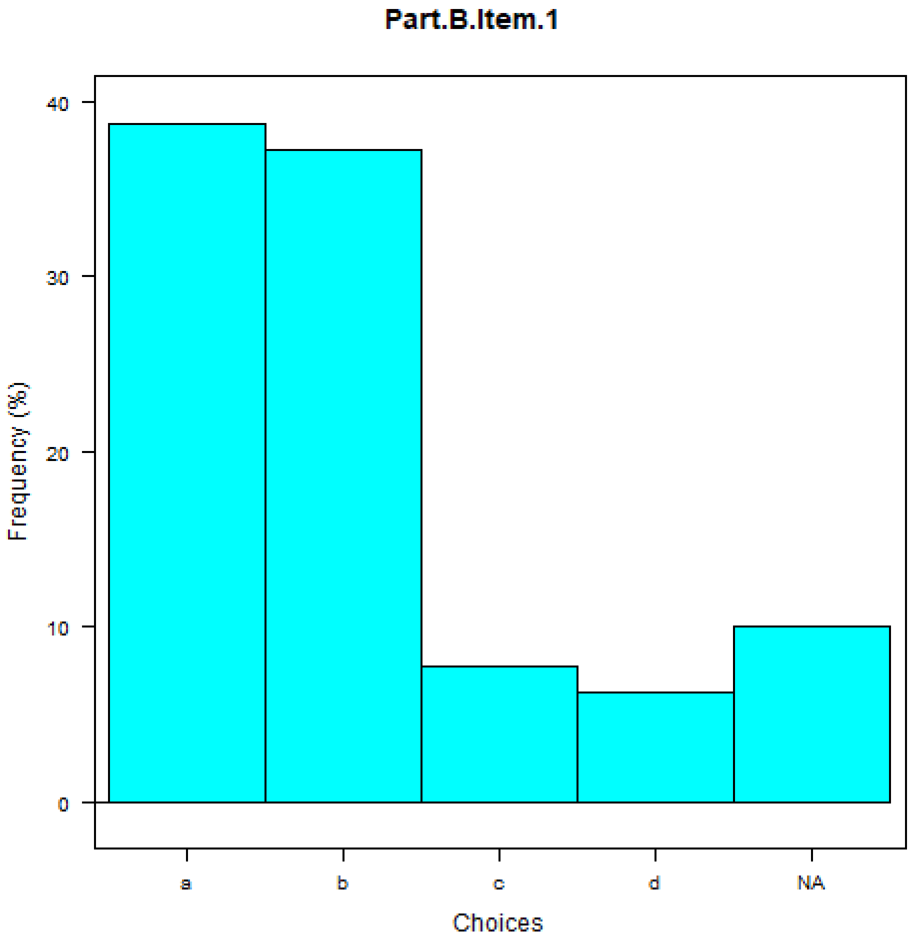
II. Merkezcil kuvvet (ipteki gerilme nedeniyle) ve taşın üzerindeki merkezkaç kuvveti Newton'un üçüncü yasasına göre eşit ve zıt yöndedir.

III. Dönen taşın gözlem çerçevesine göre, taşa etki eden merkezkaç kuvveti gerilme kuvveti tarafından dengelenir.

Merkezkaç kuvveti ipteki gerilme kuvvetini dengeleyemez çünkü merkezkaç kuvveti hayali bir kuvvettir; ipteki gerilme kuvveti gibi gerçek bir kuvveti dengeleyemez.

Appendix C

Per Item Distractor Histogram Part B

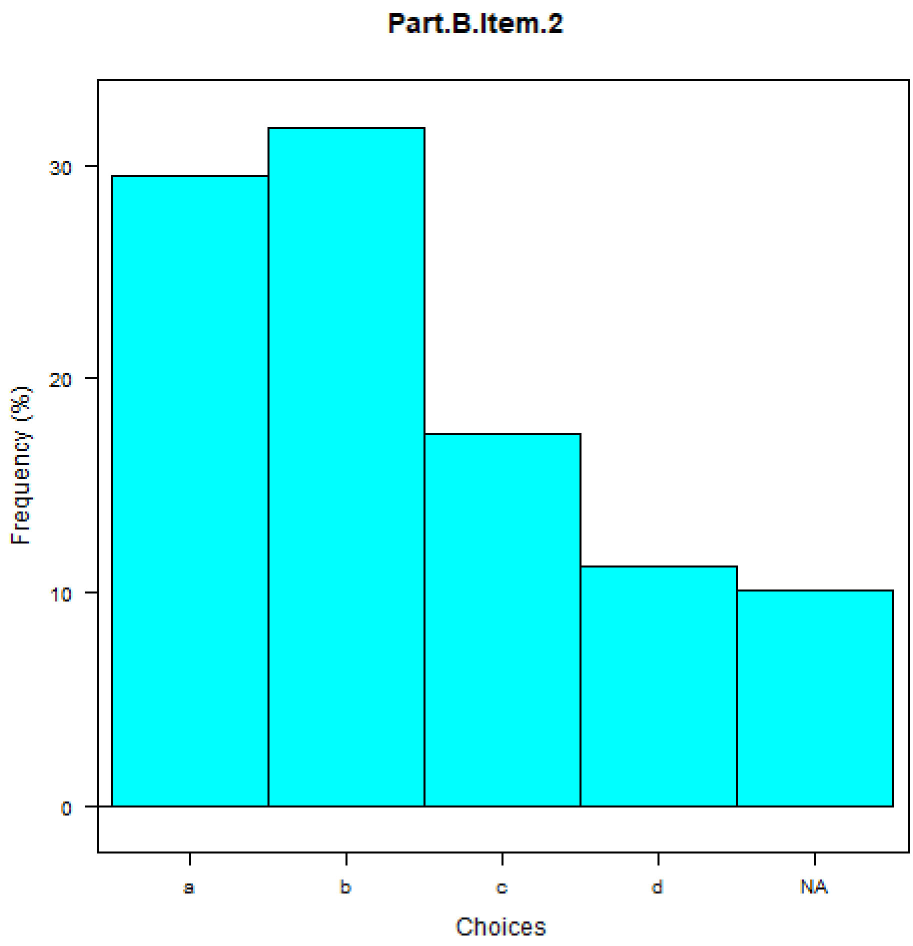


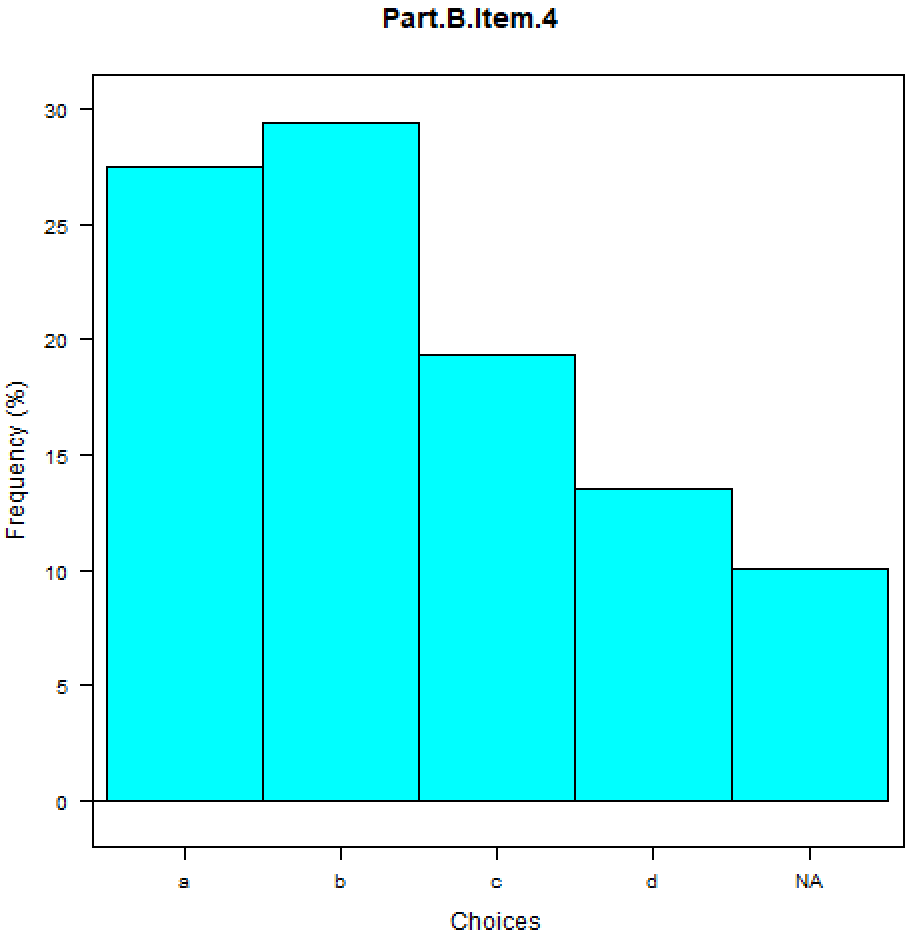
a. The statement is definitely true.

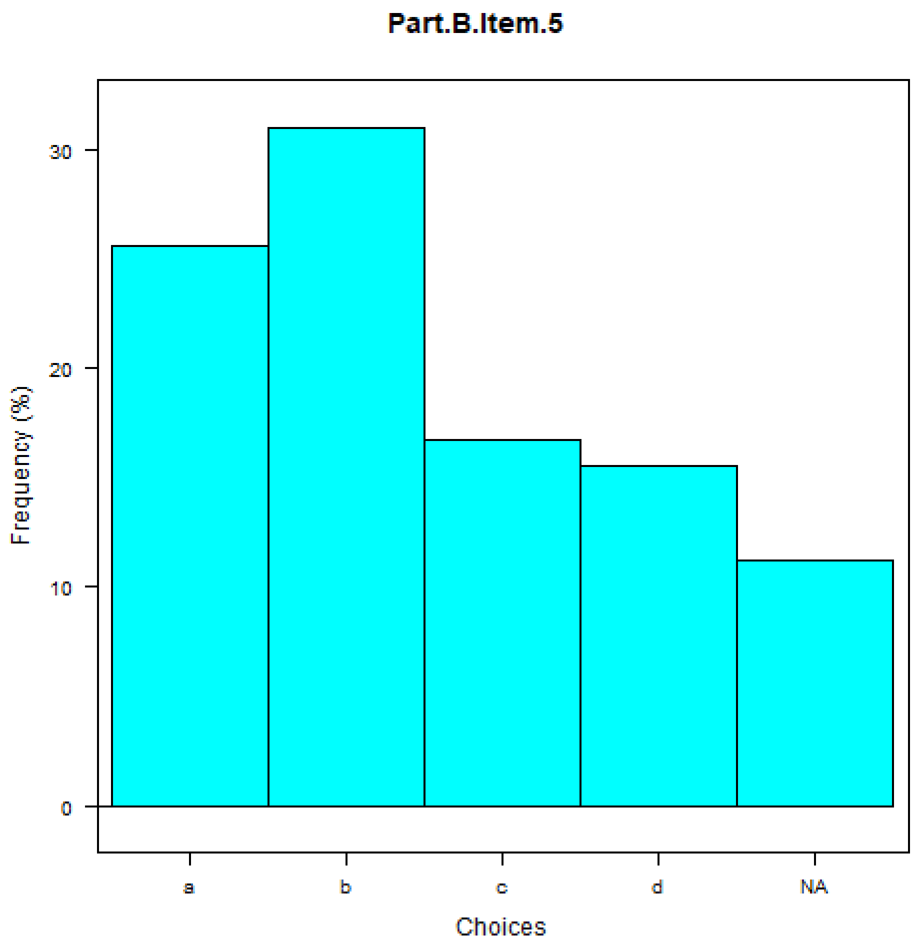
b. Not sure, but the statement might possibly be true.

c. Not sure, but the statement appears to be wrong.

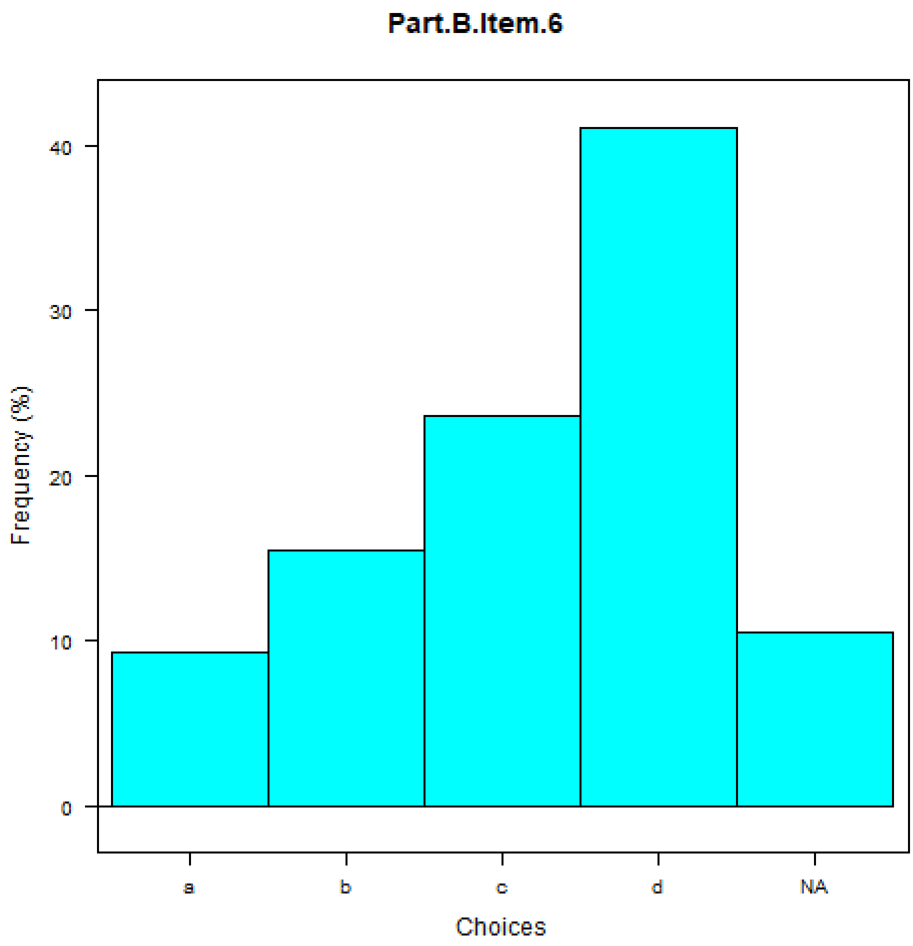
d. The statement is definitely untrue (or) it does not make sense

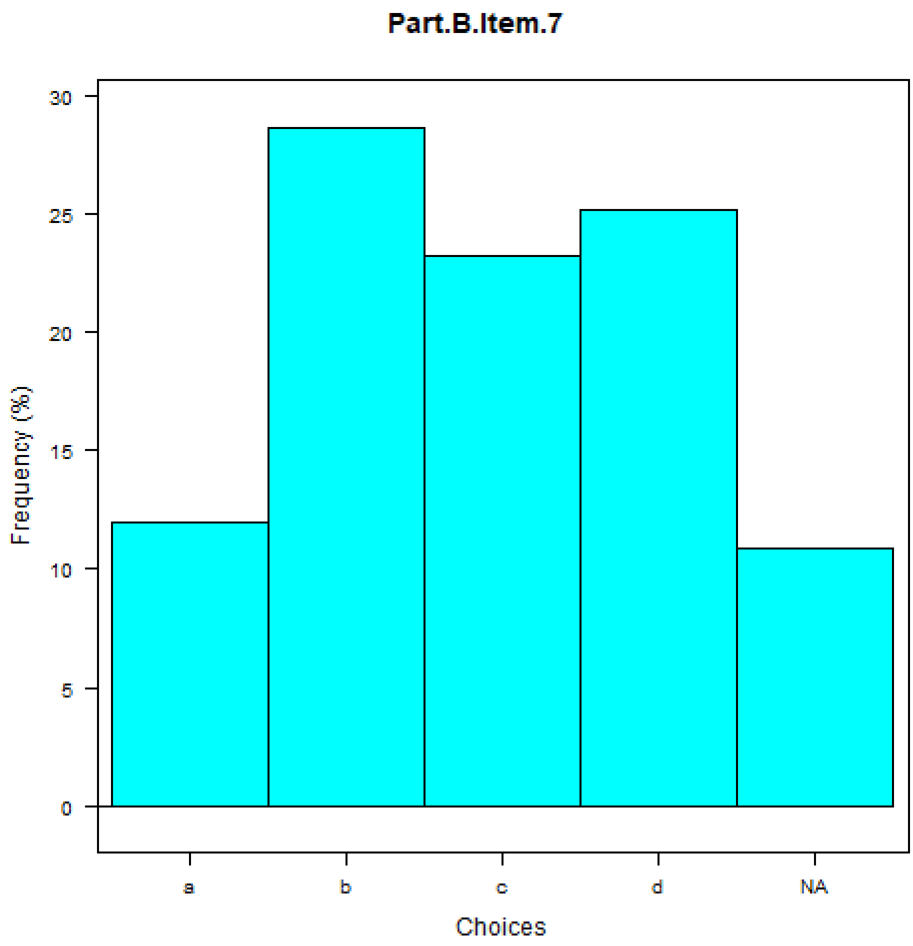

Part.B.Item.2
Frequency (%)
0
10
20
30
a
b
c
d
NA
Choices

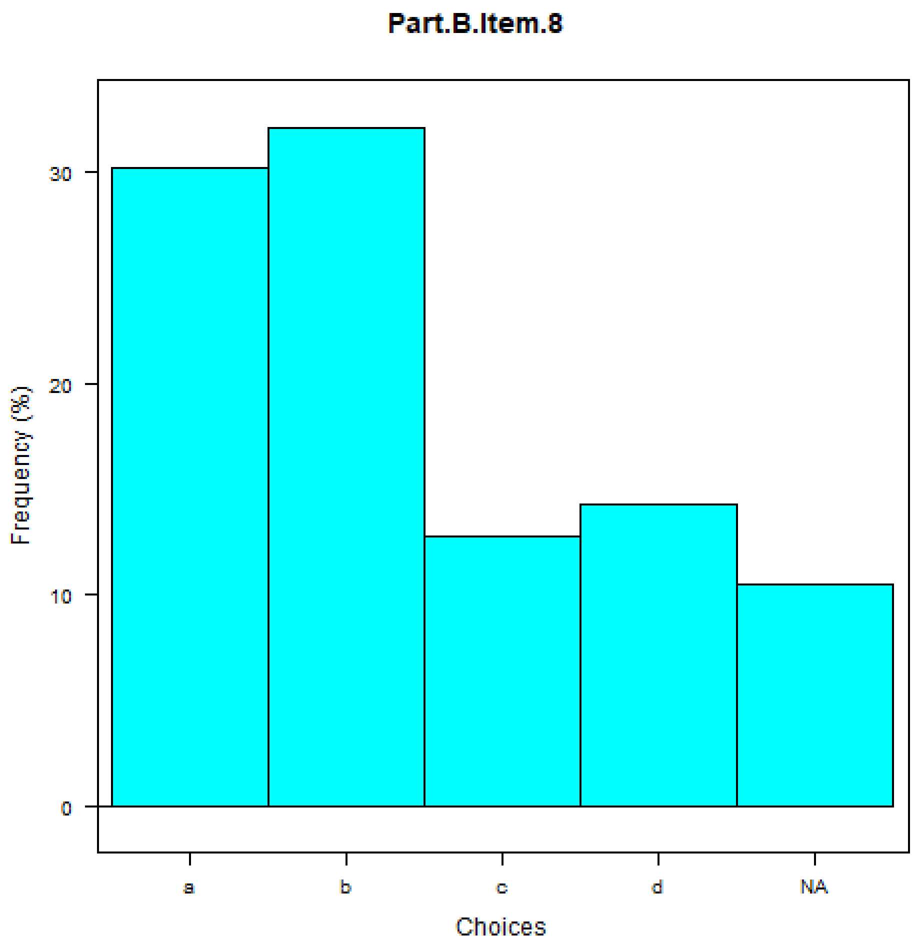

Part.B.Item.4
Frequency (%)
30
25
20
15
10
5
0
a
b
c
d
NA
Choices

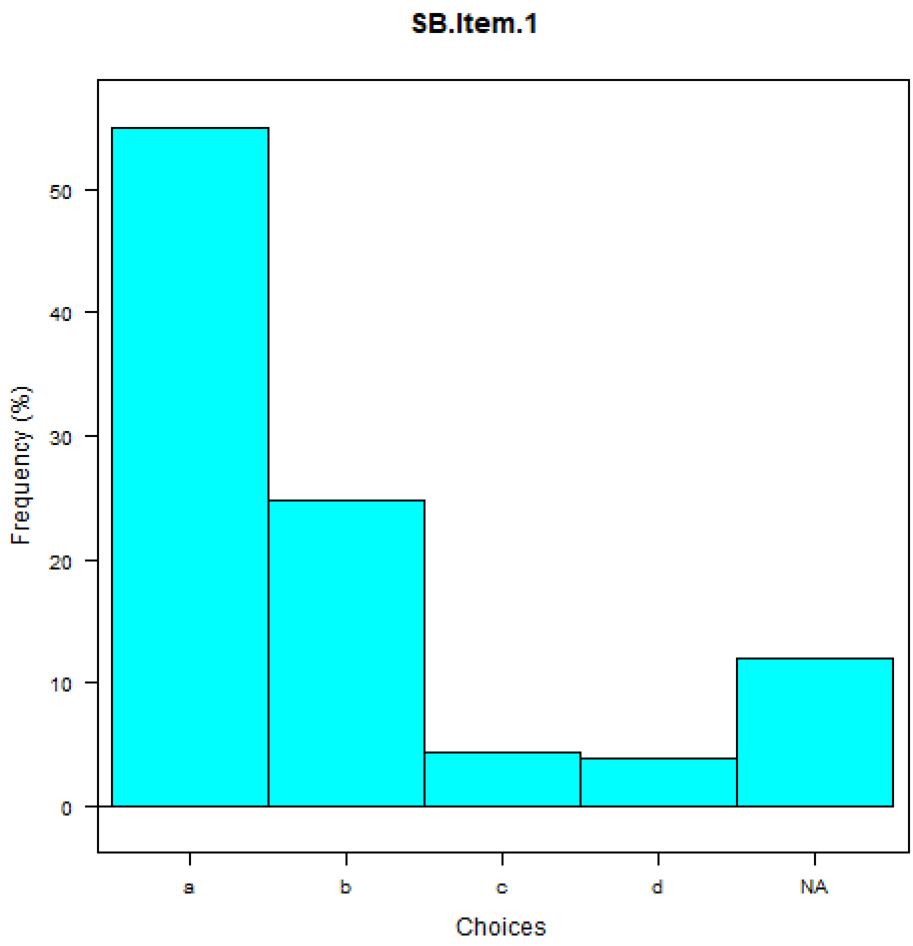


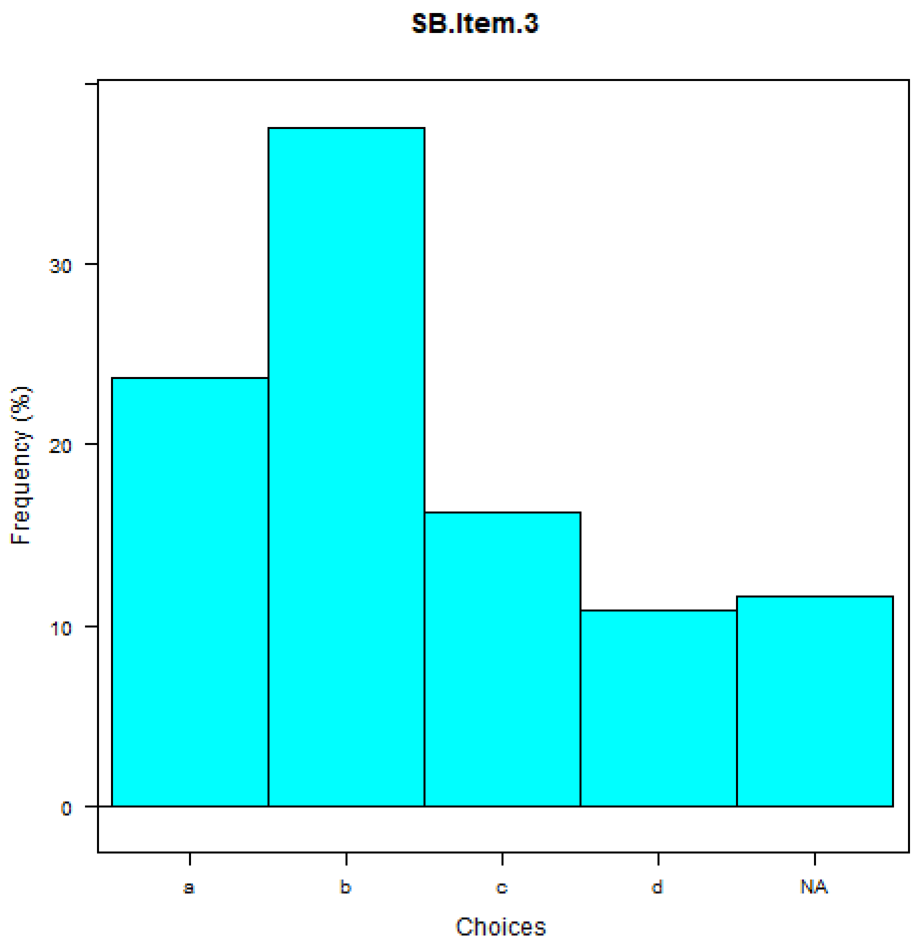
Part.B.Item.5
Frequency (%)
30
20
10
0
a
b
c
d
NA
Choices

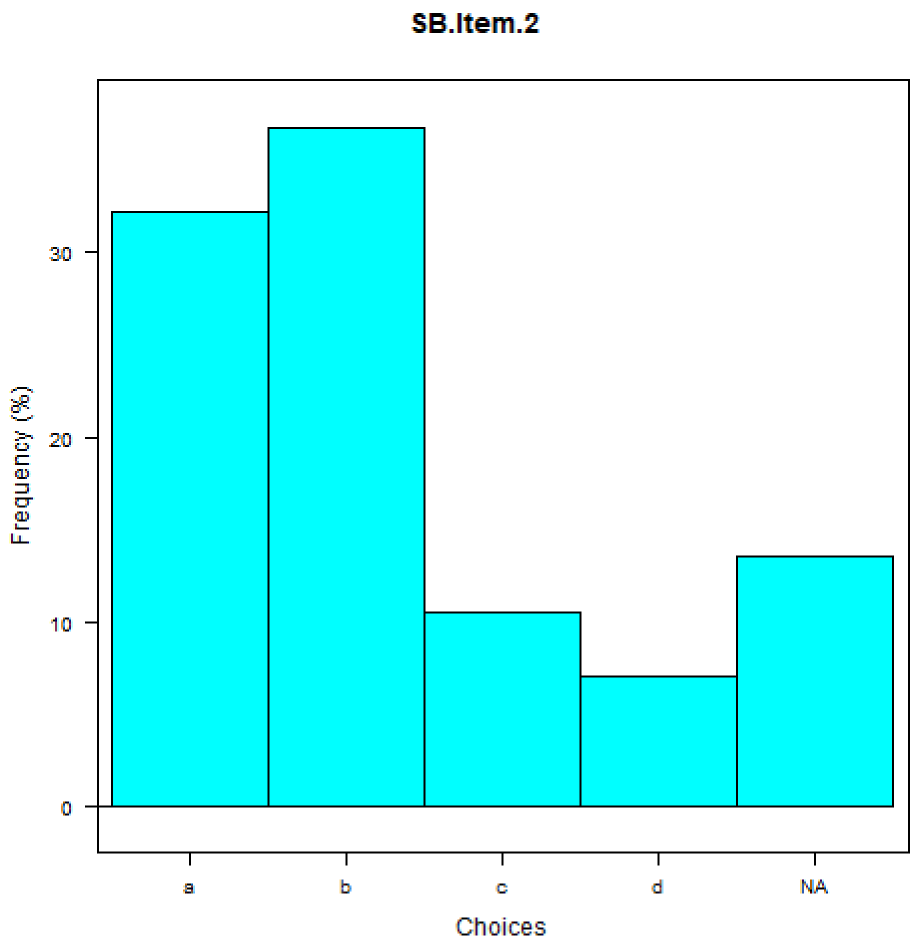

Part.B.Item.6
Frequency (%)
0
10
20
30
40
a
b
c
d
NA
Choices

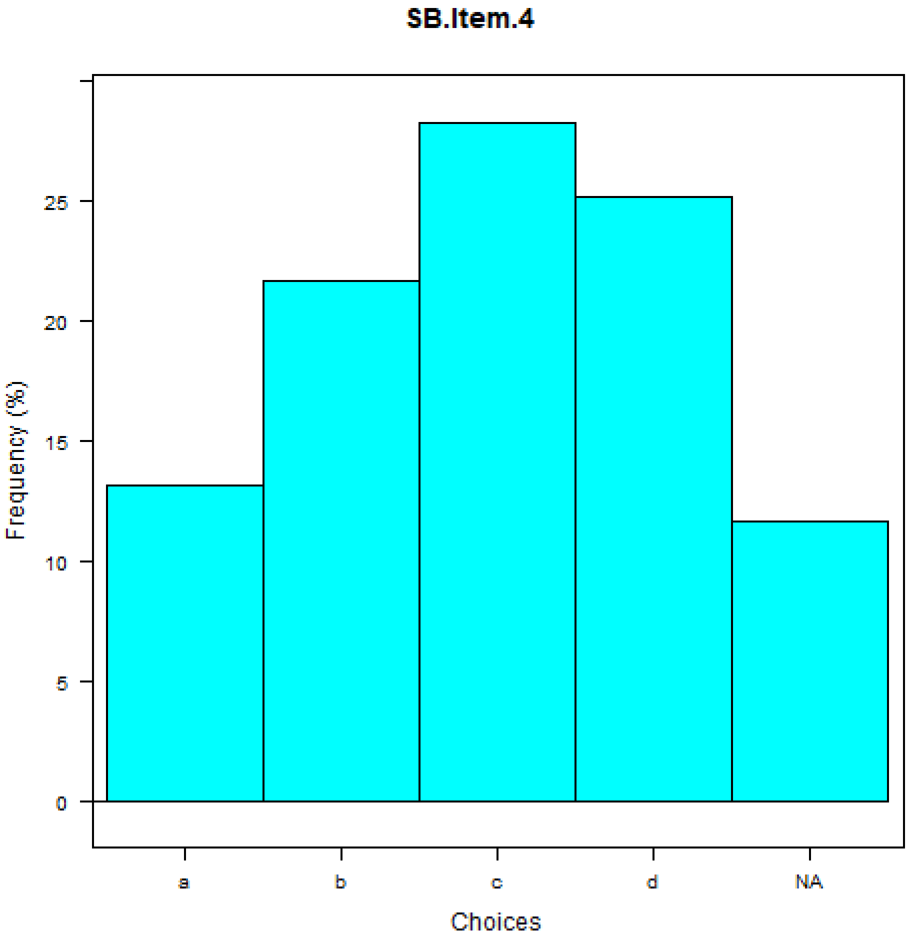

Part.B.Item.7
30
25
20
15
10
5
0
Frequency (%)
a
b
c
d
NA
Choices


Part.B.Item.8
Frequency (%)
0
10
20
30
a
b
c
d
NA
Choices


SB.Item.1
Frequency (%)
0
10
20
30
40
50
a
b
c
d
NA
Choices


SB.Item.3
Frequency (%)
0
10
20
30
a
b
c
d
NA
Choices

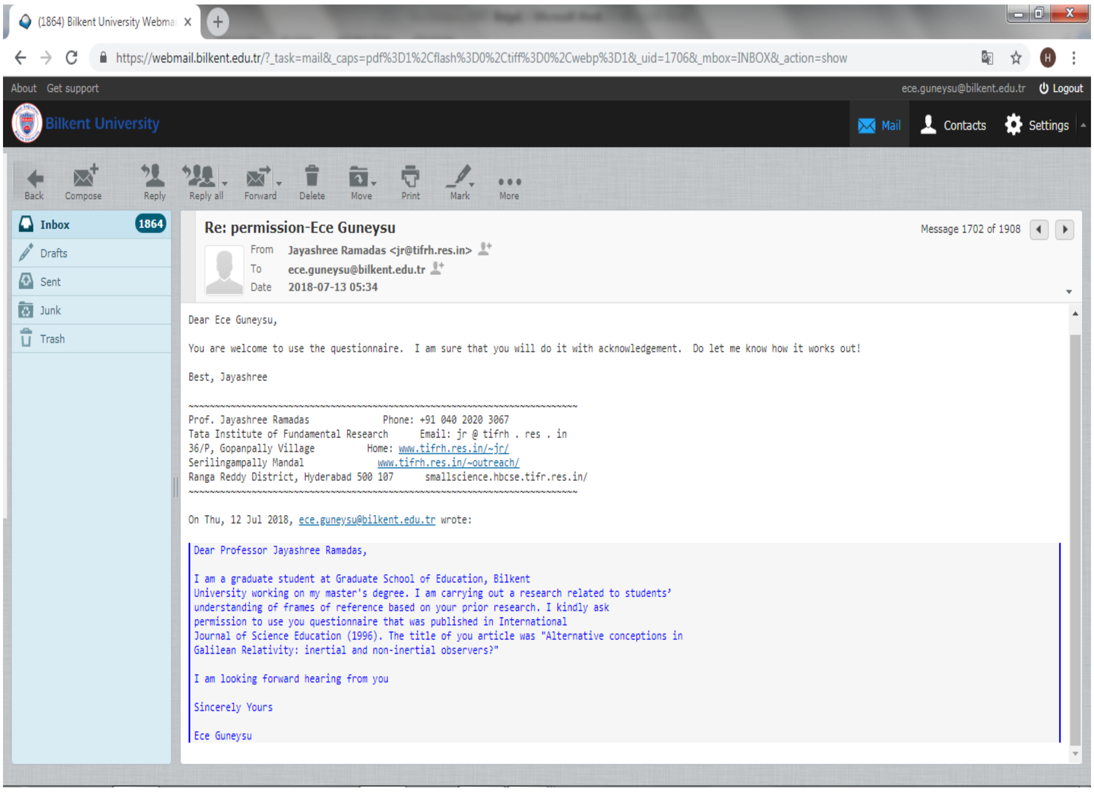

SB.Item.2
Frequency (%)
0
10
20
30
a
b
c
d
NA
Choices


SB.Item.4
Frequency (%)
0
5
10
15
20
25
a
b
c
d
NA
Choices

Appendix D

Veri Toplama Aracı Kullanım Izni

Referans Çerçeveleri Kavramını Belirleme Anketi kullanım izni, anketi geliştirenlerden biri olan Jayashree Ramadas'ın yazılı izni ile alınmıştır.



Re: permission-Ece Guneysu

From Jayashree Ramadas <jr@tifrh.res.in>
To ece.guneysu@bilkent.edu.tr
Date 2018-07-13 05:34

Dear Ece Guneysu,

You are welcome to use the questionnaire. I am sure that you will do it with acknowledgement. Do let me know how it works out!

Best, Jayashree

~~~~~~
Prof. Jayashree Ramadas Phone: +91 040 2020 3067
Tata Institute of Fundamental Research Email: jr @ tifrh . res . in
36/P, Gopanpally Village Home: www.tifrh.res.in/~jr/
Serilingampally Mandal www.tifrh.res.in/~outreach/
Ranga Reddy District, Hyderabad 500 107 smallscience.hbcse.tifr.res.in/
~~~~~~

On Thu, 12 Jul 2018, ece.guneysu@bilkent.edu.tr wrote:

Dear Professor Jayashree Ramadas,

I am a graduate student at Graduate School of Education, Bilkent University working on my master's degree. I am carrying out a research related to students' understanding of frames of reference based on your prior research. I kindly ask permission to use you questionnaire that was published in International Journal of Science Education (1996). The title of you article was "Alternative conceptions in Galilean Relativity: inertial and non-inertial observers?"

I am looking forward hearing from you

Sincerely Yours

Ece Guneysu

Appendix E

MEB Permission Letter

T.C.
ANKARA VALİLİĞİ
Milli Eğitim Müdürlüğü

Sayı : 14588481-605.99-E.5442006 14.03.2019
Konu : Araştırma izni

BİLKENT ÜNİVERSİTESİNE
(Eğitim Bilimleri Enstitüsü)

İlgi: a) MEB Yenilik ve Eğitim Teknolojileri Genel Müdürlüğünün 2017/25 nolu Genelgesi.
b) 08.03.2019 tarihli ve 3247 sayılı yazınız.

Üniversiteniz Eğitim Bilimleri Enstitüsü Yüksek Lisans Öğrencisi Ece GÜNEYSU'nun **"Ankara'nın Çankaya İlçesindeki Lise Öğrencilerinin Eylemsiz Referans Sistemi Hakkındaki Kavram Yanılgıları Üzerine Nicel Bir Çalışma"** konulu araştırması kapsamında uygulama yapma talebi Müdürlüğümüzce uygun görülmüş ve uygulamanın yapılacağı İlçe Milli Eğitim Müdürlüğüne bilgi verilmiştir.

Uygulama formunun (4 sayfa) araştırmacı tarafından uygulama yapılacak sayıda çoğaltılması ve çalışmanın bitiminde bir örneğinin (cd ortamında) Müdürlüğümüz Strateji Geliştirme Şubesine gönderilmesini rica ederim.

Mehmet ÇALIŞKAN
Vali a.
Müdür Yardımcısı

Güvenli Elektronik İmzalı
Aslı İle Aynıdır.
14.03.2019

Adres: Emniyet Mah. Alparslan Türkeş Cad. 4/A Yenimahalle
Bilgi için: Emine KONUK
Elektronik Ağ: ankara.meb.gov.tr
Tel: 0 (312) 212 36 00
e-posta: istatistik06@meb.gov.tr
Faks: 0 ( )

18.3.19
EBE

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