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Real vs virtual physics experiments: comparison of learning outcomes among fifth grade primary school students. A case on the concept of frictional force

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ABSTRACT
This paper compares students' conceptual understanding of a standard physics law, i.e. frictional force, following the execution of real vs virtual experiments. The research sample was made up of 110 fifth grade students attending a primary school in the city of Ioannina, Northwestern Greece who were randomly assigned to either the control group (55 students) or the experimental group (55 students). The control group carried out experiments with real world objects, while the experimental group used Interactive Physics simulation software. Data was collected by administering to both groups identical pre and post tests, before and after the experiments respectively and which contained six questions each. The SOLO taxonomy model was used to evaluate student answers and the findings reveal that both experimentation methods are equally effective in the conceptual understanding of frictional force.

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Conceptual understanding; comparison; real experiments; virtual experiments; primary school

Introduction

Of late, discussions amongst researchers on the role virtual, compared to real, experiments play on learning (Zacharia & Olympiou, 2011) have taken front stage. Undoubtedly, this is a new, contemporary and interesting issue in Physics Teaching (Sullivan, Gnesdilow, Puntambekar, & Jee-Seon Kim, 2017; van Joolingen, de Jong, & Dimitrakopoulou, 2007; Zacharia & Olympiou, 2011).

The literature review on this matter is divided. Certain studies defend the effectiveness of real experiments while others support the strength of virtual experiments in Physics learning and teaching (Zacharia, 2007; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011; Zacharia, Olympiou, & Papaevripidou, 2008).

Recent studies show that the learning outcomes of students performing virtual experiments are no better than those performing real experiments (Klahr, Triona, & Williams, 2007; Triona & Klahr, 2003; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011). More specifically, Klahr et al. (2007) compared how students learned about mousetrap cars after performing design experiments with physical equipment or a computer simulation. Students were limited to either a certain length of time or a certain number of trials. The researchers found no difference in the students' conceptual change, their

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ability to design cars, or their confidence in their knowledge. Similar results were found in others studies about heat and temperature (Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011).

However, previous studies have demonstrated that virtual experiments prevail over real ones in achieving students' learning outcomes (Finkelstein et al., 2005; Zacharia, 2007; Zacharia et al., 2008). More specifically, Finkelstein et al. (2005) compared how students enrolled in an algebra-based introductory physics course learned about circuits while performing physical or virtual experiments. Researchers found that students who used the simulation could build a physical circuit quicker, had better explanations of circuit behaviour, and performed better on related exam questions than students who used physical equipment (Chini, Carmichael, Rebello, & Gire, 2010).

Yet others defend that real experiments prevail over their virtual counterparts (Marshall & Young, 2006). For example, Marshall and Young (2006) found that physical experiments were more beneficial and less time consuming than using computer simulations for pre-service teachers' development of ideas and explanations about the way things work, or theories-in-action, in physics (Sullivan et al., 2017).

The concepts and phenomena that the aforementioned studies investigate mainly concern electricity and electric circuits, as well as heat and temperature. Few studies include engineering concepts (Klahr et al., 2007; Triona & Klahr, 2003) and more specifically that of friction which is a difficult and abstract nature for students to understand. Indeed, friction is a significant component of the Life Sciences Curriculum, and studies (Driver, Guesne, & Tiberghien, 1985) have found that students misunderstand this concept which means that further research is needed to address such misunderstandings via appropriate experimental – whether virtual or real – approaches according to the scientific standard.

There have been a few studies regarding the understanding of the force of friction by young children. A relevant study conducted on students aged 10–11 attempted to achieve conceptual change through a special teaching intervention in the understanding of the variables on which friction depends (Tsagliotis, 1997). According to the findings of the study, which were in agreement with those of Stead and Osborne (1981), the children were led from an intuitive approach towards weight and the nature of the surfaces in contact to an approach that recognises these two parameters as the decisive variables for frictional forces to be present.

At the same time, the literature review shows that few studies compare the conceptual understanding of frictional force alone using virtual versus real experiments. For example, Chini et al. (2010) compared the effects of real versus virtual manipulations to assess the understanding of an object's movement dynamics on ramps, thus presenting concepts such as 'length and friction', as well as 'length and height'.

Once they completed the experimental activities on 'length and friction' the results showed no significant difference in students' understanding, regardless if they used real or virtual objects (simulation). However, it is worth noting that once they completed the experimental activities related to 'length and height', students involved in the simulation experiment had better learning outcomes than those who used real objects. In other words, this research does not provide a straightforward answer as to which type of experiment is more effective. Similar results were later found in analogous research (Chini, Madsen, Gire, Rebello, & Puntambekar, 2012).

Thanks to the above research there has been increased research interest in the different benefits, and limitations, of physical and virtual experimentation, with each method of experimentation demonstrating its own benefits and drawbacks (de Jong, Linn, & Zacharias, 2013; Olympiou & Zacharia, 2012).

In this case, although the laws of friction are expressed in an easy to understand manner, these same laws conceal a plethora of microscopic phenomena whose explanation has become one of the most interesting pursuits in applied physics (Hahner & Spencer, 1998). Consequently, many investigators (Chini et al., 2010; Marshall & Young, 2006; Ringlein & Robbins, 2004; Zacharia et al., 2008) have suggested that these microscopic phenomena of frictional force should be explored using virtual experiments.

In particular, researchers (Jimoyiannis & Komis, 2001) argue that virtual experiments – using Interactive Physics – provide the ability to transform abstract concepts such as that of frictional force into perceptual representations depicted in images, motion simulations, diagrammatic representations of force vectors and numerical measurements. All of the above hold a significant pedagogical value in aiding the understanding or study of natural phenomena and processes.

Furthermore, virtual experiments provide possibilities to study natural phenomena that are difficult to reproduce in the laboratory, such as non-frictional states (Jimoyiannis & Komis, 2001; Sullivan et al., 2017; Zacharia & Anderson, 2003). As such, with virtual experiments, concepts such as kinetic energy or momentum or frictional force which cannot be directly observed, may however be represented by perceptual representations on a computer screen using Interactive Physics software (Marshall & Young, 2006).

Thanks to this software, it is possible to develop a comprehensive computer physics lab that is simultaneously supported by a powerful two-dimensional simulation environment. Users have a variety of tools at their disposal and with simple manipulations can create their experiment on the computer screen. Via the use of this software, students can easily (Jimoyiannis & Komis, 2001):

- Perform experiments and solve problems by immediately seeing their findings on the screen
- Repeat the experiment as often as necessary, according to need and level of understanding in order to create the appropriate representations and to understand the correlations among the different magnitudes
- Discover inconsistencies and become acquainted with alternative explanations to the phenomena, laws and procedures of Physics

Virtual experiments using Interactive Physics software provide the environment and experience required to develop and construct abstract ideas and concepts in Physics, such as that of frictional force (Steinberg, 2000; Zacharia & Anderson, 2003).

Regarding the importance of performing real experiments to understand frictional force, it should be noted that research uses a simple object ejector in order to detect cognitive barriers and assess how children reflect on the role of various weights and types of contact surfaces (Ravanis, 2013; Ravanis, Koliopoulos, & Boilevin, 2008; Ravanis, Koliopoulos, & Hadzigergiou, 2004).

An object ejector was used because in the pre-research phase the investigators found many children had attributed the differences in object distances to the idea that the said objects were ejected with a different initial force to that which they can tolerate (Driver et al., 1985). When using this device all children accept that the same initial force is exercised on the moving object. In this context, real experiments make it feasible for students to gain pre-existing knowledge on the meaning of frictional force and can build associations with real observations in everyday life – such as walking, starting the engine of a car, climbing a rope and holding a glass of water in one's hand. As a result, real experiments can be further strengthened with specially designed lab interventions that are based on active touch and designed to offer authentic experiences that override previous experiences and observations in the real world (Minogue & Jones, 2009).

The contradictory results that emerge from the aforementioned research, not to mention that comparisons have been made among samples of different demographic characteristics (age of participants, type of simulations), do not allow us to draw safe conclusions. Thus, one can argue that to this date a clear and empirical answer to the kind of experiment that is most effective in Physics teaching and learning is still lacking (Evangelou & Kotsis, 2009; Sullivan et al., 2017). In terms of learning outcomes, there are many studies in which virtual experiments appear to outweigh real experiments because of the additional features offered, such as the visual representation of the microcosm and, in particular, electron flow (Finkelstein et al., 2005; Jaakkola & Nurmi, 2004), graphs (Chini et al., 2010; Zacharia, 2007), time savings (Zacharia, 2007; Zacharia et al., 2008) etc.

At the same time, the literature review acknowledges that a limited number of studies show an exclusive comparison of the effect of virtual vs real experiments in Physics teaching and learning environments (Klahr et al., 2007; Triona & Klahr, 2003; Zacharia & Constantinou, 2008), where all factors that affect learning are controlled, such as the teaching approach, the teaching context, the learning environment, the timing of the experiments, the teaching material (worksheets, experimental material), or the added value that virtual and real experiments may offer. Still, even at an international level, few studies have been carried out on primary school aged children (Evangelou & Kotsis, 2009; Jaakkola & Nurmi, 2004; Jaakkola & Nurmi, 2008; Triona & Klahr, 2003).

Based on the above, there is a significant shortage in empirical studies that compare the effect of virtual against real experiments in physics teaching and learning, and particularly in primary school aged children. Consequently, the present study sets out to investigate the impact of virtual vs real physics experiments on primary school aged students on the concept of frictional force, provided that the factors influencing the learning outcomes mentioned above are consciously controlled.

Curriculum materials

Constructivism and the Predict – Observe – Explain (POE) strategy

In this study, the execution of both virtual and real experiments is based on the theory of constructivism and especially the constructivist teaching model (Driver et al., 1985), as well as the 'Predict – Observe – Explain' (POE) strategy (Hofstein & Lunetta, 2004; White & Gunstone, 1992; Zacharia et al., 2008).

According to the constructivist teaching model, in order for the experiment (virtual or real) to positively influence students' understanding of concepts and phenomena it must create, as an ulterior motive, a cognitive conflict against a student's misconception. In other words, the theory of constructivism accepts that experimentation is useful only if it causes a cognitive clash with a student's existing misconception, and thereby modifying the concept's essence to comply with the scientific model (Driver et al., 1985). Consequently, and based on the constructivist teaching model, this study shall attempt to determine which of the two types of experiments is more effective in modifying students' misunderstandings, via cognitive conflict, to achieve the corresponding scientific views.

At the same time, based on the POE strategy, students are asked before performing the experiments to predict what they expect to happen in a given situation and to record it, then to perform the experimental activities and make observations and finally, to confirm or reject what they had initially predicted.

The concept of frictional force

The concept of frictional force is an essential unit in both the Greek curriculum and Greek school textbooks of the fifth-grade primary school classroom. To date, the concept of frictional force has not been investigated in studies that compare the effect of virtual vs real experiments on learning (Evangelou & Kotsis, 2009).

In addition, other criteria considered in selecting the curriculum unit of frictional force in this study include the following: (i) presents possibilities to perform both virtual and real experiment; (ii) provides the opportunity to organise, methodologically, control and experimental groups to compare the learning outcomes of real vs virtual experiments; (iii) students encounter difficulties and misunderstandings on frictional force are frequent (Driver et al., 1985); (iv) a constructivist approach is endorsed and consequently intends to conceptually change students' misunderstandings.

Consequently, based on the above, frictional force is a challenge for both students and teachers. In order for students to gain an in-depth understanding on the force of friction and thus trigger a cognitive conflict that would allow them to modify or change their misunderstandings and endorse the scientific model, an appropriate learning environment is deemed necessary.

In the present study and for this reason, in addition to applying the principles of the theory of constructivism, the investigator built an object ejector for students in the control group (as shown in Figure 1 below) which allowed participants to accept that the same force is exerted on each ejected object (body), thus limiting any misunderstanding on the movement of objects (Ravanis et al., 2004). For students in the experimental group, a similar improvised construction was created using Interactive Physics simulation software as shown in Figure 3.

Figure 1. Ejection device/mechanism of objects.

Methods

The aim of study

The main purpose of this research study is to compare the learning outcomes and conceptual understanding of fifth-grade primary school students who perform real vs virtual experiments on the concept of frictional force. In other words, this study intends to compare the learning outcomes following the execution of virtual vs real physics experiments and in particular, demonstrate which type of experiment is more effective in modifying and altering student misconceptions on frictional force, a scientifically valid concept.

Research questions

This research explores the following two research questions:

(1) What type of experiment, virtual or real, is more effective for the conceptual understanding of frictional force in fifth-grade primary school students?
(2) What kind of experiment is more effective in achieving conceptual change, and in particular in modifying students' misunderstandings on the scientifically valid concept of frictional force?

Sample

The research sample included 110 students enrolled in a fifth-grade classroom. The study was conducted in 2012 in three different schools located in the city of Ioannina, Northwestern Greece.

These three (3) primary schools were selected via random sampling among a list of twenty-seven (27) primary schools in the city of Ioannina.

In terms of gender, the sample of 110 students consisted of 58 boys (53%) and 52 girls (47%). The statistical analysis did not show any correlations among responses and gender, therefore any further presentation of this sample's characteristics is unnecessary.

Objects

Real objects

The research is aimed at students who have little experience in performing experiments with real objects. However, for the purpose of successfully implementing the research methodology, students became familiar with the real objects prior to conducting the study. The real experiments were performed on desks where students worked in teams of two.

The real objects required to perform the actual experiments include the following:

(1) Ejection device/mechanism of objects:
    The device is made up of two parts:
    (A) A spring-loaded metal shaft. At the tip of the shaft there is a rubber cap, in which we connect a wooden parallelepiped (or any object). First, we coil the spring and then release it, pushing down the blue button on the device.

    (B) A smooth surface (made of melamine) to which the ejection device is mounted. The surface can be covered with different materials, i.e. rougher materials (such as sandpaper), in order to observe the different positions that stop the objects.

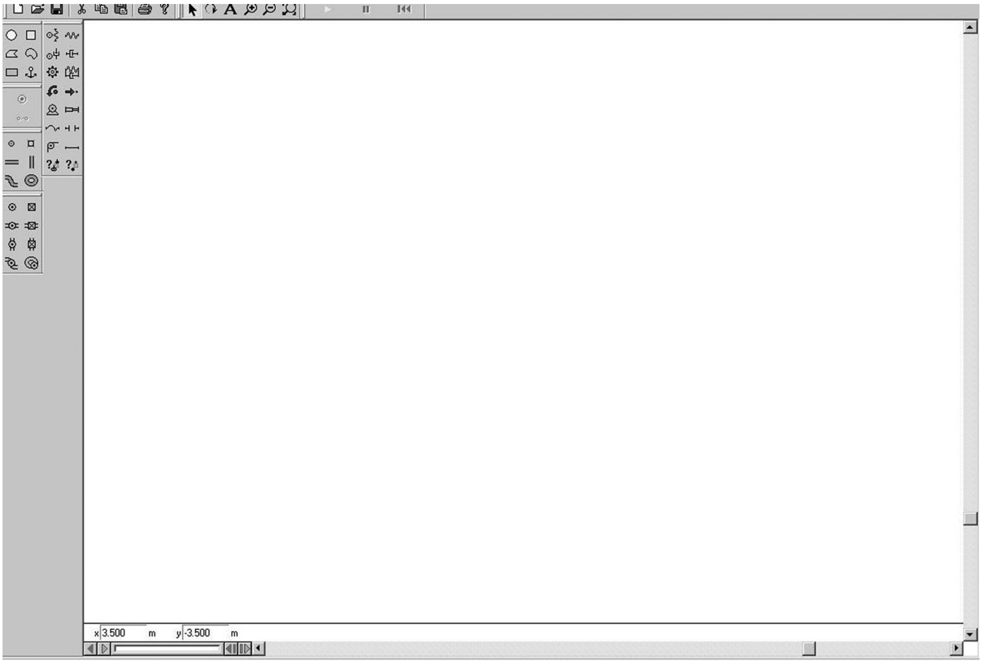
(2) Two identical wooden parallelepipeds
(3) Sandpaper (rough surface)
(4) A white and a coloured chalk

Virtual objects – simulation

This study is aimed at students with little experience in performing virtual experiments using simulation software. However, for the purpose of successfully implementing the research methodology, students became familiar with the Interactive Physics simulation software prior to conducting the study. The virtual experiments took place in the computer lab where students worked in teams of two (Figure 2).

In the present study, in order to perform the virtual experiments, a similar ejection device was created, using the Interactive Physics simulation software. This following device is depicted on the screen:

Similarly to the real objects, the device illustrated in Figure 3 is made up of two parts, identical to the real object: (A) A spring-loaded metal shaft. Initially, the student coils the spring and then releases it by pressing the Start experiment button. If the student wants to repeat the experiment, then they must press the Repeat button. (B) A wooden surface to which the ejection device is mounted. The surface can be covered with different materials that are rougher (such as sandpaper), in order to observe the different positions that stop the objects.



x 3.500 m y -3.500 m

Figure 2. Interactive Physics simulation software screen (University Department of Primary School Education, University of Ioannina).

Figure 3. The ejection device on the Interactive Physics simulation software screen.

Finally, the simulations on the concept of frictional force were designed by the investigator-teacher himself using the Interactive Physics software. These were then saved as files on the computer desktop for students to perform the virtual experiments.

Proceduce – experimental design

The study's design includes three main steps: (i) a pilot study conducted among students attending a primary school located in the district of Katsika, in Ioannina in the 2011 academic year; (ii) Using cluster random sampling three elementary schools were selected from a list of the 27 primary schools in the city of Ioannina to participate in the main study; and (iii) the implementation of the main study with fifth grade students in the city of Ioannina in 2012.

The experimental intervention involved dividing the sample, via random selection, into two equivalent groups, and a randomised controlled 'pre – test post – test' experimental design was used (Robson, 2002).

In particular, students were randomly assigned to two equivalent groups: both the experimental group and control groups consisted of 55 students. The control group experimented with real objects in a standard classroom while the experimental group used the computer lab to perform the same experiments using the Interactive Physics simulation software. It is essential to note that prior to the study's initiation students were not taught the concept of frictional force.

In the present study, the before and after experimental design for each group is represented schematically as follows (Figure 4):

The schematic description of the study's design includes the use of symbols (Cohen & Manion, 2000):

Type of group	**Experimental design**		
1: Experimental group	O_{1A}	X_A	O_{2A}
2: Control group	O_{1B}	X_B	O_{2B}

Figure 4. Stages of experimental intervention for both groups.

(1) X: Exposure of the group to the corresponding experimental variable.
(2) O: Measurement procedure.
(3) X and O at any given moment apply to the same person.
(4) The row from left to right shows a time sequence.

The teaching approach was based on the principles of the theory of constructivism. In particular, in this study's proposed learning environment and in line with addressing the misunderstandings on scientific concepts through hands-on teaching, learning is treated as a process where students replace or modify misconceptions with those that are considered scientifically valid. For this reason, in order to be able to achieve conceptual change (Zacharia, 2007; Zacharia et al., 2008) the following teaching interventions were carried out in this research: (i) preconceived notions held by students before the classroom were recorded by the researcher as a starting point prior to designing appropriate teaching methods, worksheets and didactic/experimental interventions, (ii) the conditions to formulate and control assumptions and forecasts were set out and achieved in the present research through appropriately designed worksheets and thanks to the contribution of the 'Prediction – Observation – Explanation' model, (iii) the students support their very own active learning process by performing real and virtual experiments.

An experimental method (Cohen & Manion, 2000; Klahr et al., 2007) was used throughout the design and implementation of the experimental intervention, which in turn is divided into three stages (Figure 4):

(I) The pre-test (1): students were given an initial worksheet (1) with six open questions
(II) Experimental activities [test (2) & test (3)]: this stage is divided into two sub-steps which include: (i) the predictions – assumptions worksheet (2) (test (2)) and (ii) the confirmation or rejection of predictions – assumptions after having performed real or virtual experiments (proof of experimentation) and the use of worksheet (3) – Experiments (test (3))
(III) The post – test (4): students were given the Applications worksheet (4) containing the same questions as the pre-test

The implementation of the above three steps lasted for two hours for each group separately, without any interruptions to the intervention process.

Before the execution of the experiments group comparisons were determined by assessing students' extent of knowledge using the Tukey HSD statistical test (Table 7). To carry out this assessment, the questions in the pre (1) and post (4) tests for both the virtual and real experiments were exactly the same for the two groups.

It is important to point out that during this comparison, the two groups of students participating in the research were treated similarly in terms of the objectives they needed to fulfil, the content and time limit. Throughout the study phase, specific factors influencing learning were controlled such as the didactic approach, teaching context, learning environment, teaching materials (worksheets, experimental material) and the added value that virtual and real experiments offer.

The educational targets and research experiments

In terms of the study's teaching objectives, following the implementation of virtual and real experiments, students seek to:

- Experimentally discover and observe that the frictional force exerted on a moving object depends on the nature of the material on which the object moves
- Experimentally discover and observe that the frictional force depends on the weight of the object moving on a fixed horizontal plane
- Experimentally discover and observe that the frictional force does not depend on the size of the material with which the object rests on the fixed horizontal plane
- Make predictions – assumptions, observations, experimentally verify predictions and assumptions through evidence based experimentation, and be able to draw conclusions
- Modify their misconceptions in order to accept a scientifically valid understanding of frictional force (conceptual change)
- Be able to discern and explain the effects of frictional force in everyday life

In order to achieve the above-mentioned teaching objectives, three different experiments were carried out in this study.

(1) First experiment: Using the ejection device, students perform activities aimed at experimentally discovering and observing that the frictional force exerted on a moving object depends on the nature of the material on which the object moves. More specifically, students carry out two experimental activities here: (i) In the first activity they place a wooden parallelepiped on the smooth material of the ejection device's surface and eject it; (ii) In the second activity students cover the entire surface of the device with sandpaper (rough – abnormal material). Then they place the same wooden parallelepiped for a second time and eject it. After these two experimental activities, they compare the distances travelled by the wooden parallelepipeds and draw the corresponding conclusions

(2) Second experiment: Using the ejection device students perform activities aimed at experimentally discovering and observing that the frictional force depends on the weight of the object moving on a fixed horizontal plane. More specifically, students carry out two experimental activities here as well: (i) In the first activity they place a wooden parallelepiped on a smooth material of the ejection device and eject it; (ii) In the second activity they increase the weight by placing an equivalent second wooden parallelepiped on the first wooden parallelepiped and eject them both. After these two experimental activities, they compare the distances travelled by the wooden parallelepipeds and draw the corresponding conclusions.

(3) Third experiment: Using the ejection device students perform activities aimed at experimentally discovering and observing that frictional force does not depend on the area (size) of the surface with which the object rests on the fixed horizontal plane. Similarly, to experiments 1 and 2 students carry out two activities in experiment 3 as well: (i) In the first activity students place a wooden parallelepiped with its large side positioned on the smooth material of the ejector and eject it; (ii) In the second activity they place the smaller side of the wooden parallelepiped on the

surface and eject it. After these two experimental activities, they compare the distances the wooden parallelepipeds travelled and draw the corresponding conclusions.

Data collection

The data collection tools were conceptual understanding tests (pre-test (1) and post-test (4)) and worksheets [test (2) and test (3)], given to both groups during and after the experimental phase.

It should be noted that the conceptual understanding tests and worksheets distributed to both groups were identical in terms of the questions and experimental activities expected. Only the way in which the groups performed the experiments differed. Students, individually performed the experiments and completed the conceptual understanding tests and worksheets, despite having worked in teams in the classroom or in the computer lab.

More specifically, each worksheet distributed to each student is divided into four individual sheets, which include:

(A) Initial sheet [pre-test (1)]: There are six open-ended questions on this worksheet based on the constructivist teaching model phase where students are asked to elaborate on their reasoning.
(B) Predictions sheet [test (2)]: This worksheet includes prediction questions and was completed before the experiments were carried out. The Predictions worksheet is based on the phases of idea development and testing.
(C) Sheet of experiments (3) [test (3)]: This worksheet provides instructions for performing the experiments, includes observation questions, as well as comprehension questions on the experiments and supports the idea testing phase and acquisition of scientific knowledge.

(D) Final Applications sheet (4) (post-test 4): The same six open-ended questions on this worksheet are identical to the initial worksheet. The Final Applications sheet is based on the application of the scientific knowledge phase.

It should be noted that prior to performing the experiments, all groups were requested to complete the pre – test (1), which was identical to the post – test (4) after the experimental activities were performed. Therefore, the pre – test (1) and post – test (4) were used to evaluate and statistically analyze student responses.

The six questions contained in the pre-test (1) and post-test (4) are listed in the Appendix.

Data analysis

The evaluation of student responses before and after performing the real and virtual experiments was done according to the Biggs and Collis (1982) Structure of the Observed Learning Outcomes (SOLO) model. The SOLO taxonomy model is based on the theory that knowledge is gained through building blocks. It is a powerful tool that determines a person's current operational level and conceptional knowledge through written or spoken answers, which can be applied to any subject area and provides the ability to evaluate and categorise students' performance (Padiotis & Mikropoulos, 2010). Based on the SOLO taxonomy, a response can be integrated into one of the following five (5) hierarchical levels:

(1) Prestructural: Students do not provide an answer, or they provide the incorrect answer without giving any explanation for their choice, or they provide the incorrect answer due to incorrect associations.
(2) Unistructural: Students make simple and obvious associations but do not demonstrate the relationship among these associations
(3) Multistructural: Students make several associations but do not demonstrate the relationship among these associations
(4) Relational: Students demonstrate the relationship between associations and the relationship between the associations and the end result
(5) Extended abstract: Students make associations outside the subject area, generalise and transfer laws-relationships from the specific to the general

It is worth noting that the SOLO taxonomy is the adequate tool that categorises students' pre-test (initial worksheets (1)) and post-test (worksheets (4) – Applications) answers. As discussed below, the SOLO taxonomy was applied consistently to all study data derived from students' responses to the 6 questions listed in the appendix.

In the present study and based on the above classification, student answers were graded using the first four hierarchical levels as these take into account the degree of answer elaborateness. The four SOLO taxonomy levels in this study include: (1) Prestructural, (2) Unistructural, (3) Multistructural and (4) Relational. Answers that meet the requirements of the SOLO taxonomy extended abstract level (level 5) were not observed in any of the pre or post test questions.

Regarding this particular study, the SOLO taxonomy applied to an answer of the first (1) question is as follows:

(1) Prestructural: Students do not provide an answer, provide the incorrect answer without giving any explanation for their choice, or they provide the incorrect answer by making an irrelevant association between the type of footwear we should wear and climbing snow-covered mountains to reduce the risk of slipping.
(2) Unistructural: The answer on the type of footwear we should wear when climbing snow-covered mountains to reduce the risk of slipping, only focuses on one, out of the three required factors. Hence, the answer is geared either on the type of footwear, or the frictional force, or on the smooth surface (snowy) that the footwear rests on.
(3) Multistructural: The student chooses two or more factors however simply lists these and ignores their associations.
(4) Relational: The student lists all the factors, makes the appropriate associations and draws a conclusion, demonstrating an understanding that frictional force is greater when footwear have a rough sole as opposed to a soft sole therefore making the risk of slipping smaller.

An example of a student's answer (Student92), in the control group, for question (1) based on the SOLO taxonomy is as follows: 'Shoes with soft soles because they have a better grip when walking in snow'. This answer recorded in the pre-test was classified at the pre-structural level. Then, after the experimental intervention, the response recorded by the same student in the post – test was ranked at the relational level and includes: 'Shoes with a rough sole, as opposed to a smooth sole, because there is greater friction on snow and therefore we don't slip'.

In question (2) the student's (Student125) answer, in the experimental group, recorded in the pre-test was ranked at the unistructural level and includes: 'It's wrong, because the weight will remain the same'. Following the experimental intervention, the response recorded in the post – test was ranked at the relational level: 'It's wrong because the weight is the same regardless of which side the box is positioned, and the same goes for friction'.

In question (3) the student's (Student6) answer, in the control group, recorded in the pre-test was ranked at the unistructural level and includes: 'Old tires skid, while new ones don't skid'. Following the experimental intervention, the response recorded in the post – test was ranked at the relational level: 'New tires are more rugged than older ones and therefore the car does not skid because there is greater friction'.

In question (4) the student's (Student8) answer, in the control group, recorded in the pre-test was ranked at the unistructural level and includes: 'Because snow is smooth, and tires will skid'. Following the experimental intervention, the response recorded in the post – test was ranked at the relational level: 'The tires become rougher and there is greater friction on snow and the car does not skid'.

In question (5) the student's (Student157) answer, in the control group, recorded in the pre-test was ranked at the unistructural level and includes: 'When driving, tires rub on concrete however they skid on ice'. Following the experimental intervention, the response recorded in the post – test was ranked at the relational level: 'When driving on concrete because concrete is a rough surface and there is greater friction'.

In question (6) the student's (Student123) answer, in the experimental group, recorded in the pre-test was ranked at the unistructural level and includes: 'When loaded because it's heavier'. Following the experimental intervention, the response recorded in the post – test was ranked at the relational level: 'When it's loaded, because it's heavier and it has greater friction and it does not skid'.

The analysis of the pre and post – tests classified the answers of the fifth-grade students according to the SOLO levels for each of the six questions as shown in the Tables 1–6:

Finally, linear models were generally used for the data analysis, and Tukey's HSD multiple comparison tests were performed to detect statistically significant differences between

Table 1. Recording (Absolute and Relative Frequency) of the SOLO based cognitive levels (pre – post) of fifth grade students per group type for question (1).

	Pre-test				Post-test			
	Experimental		Control		Experimental		Control	
Level	Fr.*	Per.* (%)	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)
Prestructural	6	10.9	5	9.1	1	1.8	0	0
Unistructural	46	83.6	47	85.5	22	40.0	11	20.0
Multistructul	2	3.6	2	3.6	1	1.8	1	1.8
Relational	1	1.8	1	1.8	31	56.4	43	78.2

*Fr. = Frequency; *Per. = Percent.

Table 2. Recording (Absolute and Relative Frequency) of the SOLO based cognitive levels (pre – post) of fifth grade students per group type for question (2).

	Pre-test				Post-test			
	Experimental		Control		Experimental		Control	
Level	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)
Prestructural	49	89.1	50	90.9	0	0	5	9.1
Unistructural	4	7.3	3	5.5	4	7.3	15	27.3
Multistructul	2	3.6	2	3.6	6	10.9	11	20.0
Relational	0	0	0	0	45	81.8	24	43.6

Table 3. Recording (Absolute and Relative Frequency) of the SOLO based cognitive levels (pre – post) of fifth grade students per group type for question (3).

	Pre-test				Post-test			
	Experimental		Control		Experimental		Control	
Level	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)
Prestructural	34	61.8	34	61.8	4	7.3	3	5.5
Unistructural	19	34.5	19	34.5	13	23.6	11	20.0
Multistructul	2	3.6	2	3.6	13	23.6	9	16.4
Relational	0	0	0	0	25	45.5	32	58.2

Table 4. Recording (Absolute and Relative Frequency) of the SOLO based cognitive levels (pre – post) of fifth grade students per group type for question (4).

	Pre-test				Post-test			
	Experimental		Control		Experimental		Control	
Level	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)
Prestructural	45	81.8	45	81.8	9	16.4	8	14.5
Unistructural	3	5.5	3	5.5	8	14.5	1	1.8
Multistructul	7	12.7	7	12.7	22	40.0	27	49.1
Relational	0	0	0	0	16	29.1	19	34.5

Table 5. Recording (Absolute and Relative Frequency) of the SOLO based cognitive levels (pre – post) of fifth grade students per group type for question (5).

	Pre-test				Post-test			
	Experimental		Control		Experimental		Control	
Level	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)
Prestructural	29	52.7	29	52.7	1	1.8	3	5.5
Unistructural	22	40.0	22	40.0	24	43.6	13	23.6
Multistructul	0	0	0	0	0	0	2	3.6
Relational	4	7.3	4	7.3	30	54.5	37	67.3

Table 6. Recording (Absolute and Relative Frequency) of the SOLO based cognitive levels (pre – post) of fifth grade students per group type for question (6).

	Pre-test				Post-test			
	Experimental		Control		Experimental		Control	
Level	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)	Fr.	Per. (%)
Prestructural	25	45.5	25	45.5	1	1.8	0	0
Unistructural	26	47.3	26	47.3	22	40.0	7	12.7
Multistructul	3	5.5	3	5.5	2	3.6	4	7.3
Relational	1	1.8	1	1.8	30	54.5	44	80.0

Table 7. Group comparison of answers for the six questions using the Tukey HSD test criterion – Overall gain score.

			Tukey HSD test; Pooled MSE = 7.5835, df = 211.39			
Cell No.	Group	COM*.	{1} 9.0909	{2} 18.945	{3} 9.0909	{4} 19.873
1	Experimental	Pre		0.000138	1.000000	0.000008
2	Experimental	Post	0.000138		0.000008	0.289944
3	Control	Pre	1.000000	0.000008		0.000138
4	Control	Post	0.000008	0.289944	0.000138	

*COM. = COMBINED.

the categories of the independent variables. In all cases, results with an observed level of significance $\alpha < 0.05$ were considered statistically significant. The analysis was performed using the STATISTICA 8.0 statistical package.

Results

By processing the pre-test (1) and post-test (4) answers, pre-post average values were calculated. The scores have been combined and an overall score has been computed for the six different tests. The statistical analysis of the two groups for the six different questions is shown in Table 7:

Table 7 shows that for the six questions, the mean value of the control group's performance in the post-test completed after the experiment was 19,873 and for the experimental group it was 18,945. This difference, according to the Tukey HSD test criterion, was not statistically significant [$p = 0.2899 > 0.05$]. The control group has same performance as the experimental group after the experiments.

Discussion

Focusing on the study's research questions and based on the above findings no substantial difference in conceptual understanding between the students performing virtual experiments vs those performing real experiments on the concept of frictional force was found. In other words, there is almost an equivalent shift in understanding for both groups (Tables 1–6), i.e. from the two lower SOLO taxonomy cognitive levels (i.e. Prestructural, Unistructural) to the two upper levels (Multistructural, Relational). In addition, this means that there is no significant difference in the proportion of student misconceptions among the two groups that eventually approach, and become compatible with the scientific model. From the perspective of the SOLO taxonomy model, a Multistructural level answer comes close to the scientific model while the latter completely identified with a Relational level answer.

Recent literature reviews also confirm similar findings and therefore recognise the importance of both virtual and real experiments in understanding physics concepts and phenomena (Hofstein & Lunetta, 2004; Zacharia, 2007; Zacharia et al., 2008; Zacharia & Olympiou, 2011). In other words, to teach concepts such as frictional force, it is possible to use either a virtual or real experiment, as well as a combination of both, when students undertake individual Physics activities (Olympiou & Zacharia, 2012, 2014; Zacharia & de Jong, 2014; Zacharia & Michael, 2016).

This final conclusion is also evidenced by the different learning outcomes to the six pre and post test questions. For example, teaching topics relating to the type of material as being the factor which frictional force depends on is as effective on learning outcomes regardless if experiments include virtual or real objects.

In addition, teaching topics related to object weight as being the factor which frictional force depends on renders greater learning outcomes when it involves performing experiments with real objects. In this case, the real experiments show greater advantages thus confirming certain benefits, such as the simultaneous involvement of all human senses, the tangible experiences of touch, smell and taste (natural materials) and the potential to develop practical and kinesthetic skills (Zacharia & Olympiou, 2011).

However, teaching topics related to material size as being the factor from which the frictional force does not depend on is more effective on learning outcomes when it involves performing experiments with virtual objects. In this case, virtual experiments show greater advantages, thus confirming certain benefits such as minimising errors, flexible time management, the ability to provide additional support to understand abstract concepts and phenomena (Triona & Klahr, 2003; Zacharia et al., 2008).

Consequently, one can argue that virtual objects should be used and therefore replace real objects only in experiments where real objects and tools make teaching more complicated and do not help students to achieve accurate measurements and observations (Marshall & Young, 2006; Sullivan et al., 2017). For example, in this study's experimental activity on frictional force, the measurement of the distances of two wooden objects where on one occasion the long side touches the smooth surface of the ejection device (material) and on the next occasion the small side does the same, it was found that in the real experiment the absolute identification of the distances between the two wooden objects was not achieved after their ejection from the ejection device, prompting students to repeat the experiment more than once to achieve the expected results. Instead, with the use of virtual objects and Interactive Physics simulation software the identification of the objects' distances was achieved with absolute precision, which contributed to greater learning outcomes as shown from students' answers to the corresponding question. Therefore, only in this single exercise is it preferable and more efficient to use the virtual experiment only.

So, the findings from this research lend support for the idea that if there is limited time, having students engage in a virtual experiment, where data collection is less messy, might be more effective than a physical one for learning about physics within the topic of frictional force (Sullivan et al., 2017).

At the same time, it is worth noting that similar learning outcomes from students in the control and experimental groups make it possible to assert that virtual experiments are not less effective in comparison to real experiments on frictional force. These results provide clear indications to disclaim that virtual experiments do not provide an added contribution to the development of conceptual comprehension as opposed to real ones. Therefore, the argument that states only real experiments are conducive to learning raises doubt (Olympiou & Zacharia, 2012; Sullivan et al., 2017; Zacharia & Constantinou, 2008; Zacharia & de Jong, 2014; Zacharia et al., 2008).

Finally, in order to draw safer conclusions on the use and manipulation of either the virtual or real experiment when teaching Physics concepts and phenomena in primary school students, it is necessary to conduct further research into other important

Primary School Curriculum concepts, such as the concept of water boiling, light reflection, simple electric circuitry etc.

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Appendix

Pre – test (1) & Post – test (4)

(1) Assume that you are going to climb a snowy mountain. Would you choose to wear shoes whose soles are smooth or shoes whose soles are rough? Justify your answer

(2) Two students trying to push wooden box. One of the students tells his classmate:

> 'We cannot push it'.

The classmate replies:

> I have an idea! Let's turn the box upright. So, the small surface will touch the floor, resulting in the friction being smaller than when the large surface was touching the floor. This, then, will help us push the wooden box. (Apostolakis et al., 2006)

Please comment on the classmate's idea. Is his logic correct or incorrect? Justify your answer.

(3) Why should we use new car tires? What problem occurs if old tires travel on a smooth surface?

(4) When it snows, why should we place chains on car tires (Apostolakis et al., 2006)?

(5) Choose and circle the correct answer to the following question:

> 'When does greater frictional force develop?'

(a) When a car is driven on concrete.
(b) When driving on an icy road.
(c) I do not know.

Justify your answer.

(6) Choose and circle the correct answer to the following question:

> 'When does a car travel safely on an icy road':

(a) When it is empty.
(b) When it is loaded.
(c) I do not know.

Justify your answer.