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COMPARING THE USE OF DYNAMIC AND STATIC VISUALIZATIONS ON STUDENT MISCONCEPTIONS REGARDING MECHANICS TOPICS IN PHYSICS

MA thesis

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Abstract

Comparing The Use Of Dynamic And Static Visualizations On Student Misconceptions Regarding Mechanics Topics In Physics

Numerous misconceptions exist on how forces are taught and learned in physics. This complicates students' comprehension of the subject. The goal of this study is to examine the impacts of dynamic and static visualizations on students' comprehension of forces using quantitative analysis and a quasi-experimental design involving randomly selected groups of 11th graders (n=60). On the pre-test, students in the experimental group who were exposed to dynamic visualization scored statistically significantly higher than students in the control group (65.3% vs. 57.7%, $p<0.05$), and the post-test revealed the same result (78.85% vs. 65.35%, $p<0.05$). The findings indicate that dynamic visualizations enhance students' performance and help correct students' misconceptions about forces.

Keywords: Static visualizations, dynamic visualizations, Blender, physics, Force Concept Inventory (FCI).

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Introduction

General overview of the use of visualizations in science learning

Any visualization utilized in an educational setting (e.g., textbook, books, films, etc.) aimed at facilitating the translation of information into knowledge (Bartz, 2016). To create meaningful visualizations, it is vital to consider what the learner already understands, which is critical in the educational context (Segenchuk, 1997). Knowledge representation, including internal and external representations, is the basic concept of the visualization related to the learner's knowledge (Gilbert, 2008). Maps and graphs are examples of external representations that condense concepts in distinctive, systematic ways to make them easier to perceive and comprehend than their original forms (for example, a bar graph's collected data) (Gilbert, 2005). The internal representation, on the other hand, is seen in the world but is preserved in the mind of the audience or student. When a learner processes abstract ideas, solves problems, and makes judgments, one form of mental activity occurs: internal representation (Kurby & Rapp, 2008). Because these two forms of representations necessarily interact in a variety of ways during students' learning experiences, the distinction between exterior and interior representations is crucial both conceptually and operationally. It is also placed in a mixed, interactive and/or MOOC setting to help study learning behavior and to build, assess and provide feedback on the teaching process (Atapattu et al., 2016; Chen et al., 2016; Muoz-Merino et al., 2015). Related MOOC data study concentrates on strategies for teaching (Chen et al., 2016), use of ornamentation (MuozMerino et al., 2015; Atapattu et al., 2016). Chenet al. (2016), for example, has established a robust method to provide teachers or educators with an opportunity to evaluate top segments or videos that produce several streams of clicks. The goal of these views was to alert instructors of video issues, as the projected peaks reveal. The case study given by Muoz-Merino et al. (2015) showed how various visualizations in and among MOOC courses might help academics make quick and informed decisions. The findings of the case study show that visualizations enable teachers to quickly compare a large number of students, which visualized metrics, can assist teachers in determining the effectiveness of students' activities, and that these metrics can assist teachers in understanding how students used video lectures. Furthermore, DropoutSeer is a visual analytics framework developed by Chen et al. (2016) that not only assists instructors and education professionals in detecting dropout concerns, but also allows researchers to identify critical features that could improve the models' performance. MOOCs also provide discussion forums, which is something worth noting. Discussion boards can be difficult to administer and to grasp if many students discuss a problem (Vieira et al., 2018). Atapattu et al. (2016) performed a subject evaluation with an accessible material visualization dashboard on conversational materials from three separate MOOC courses. Users can control several components of the analysis such as votes, ideas, teachers' answers and analysis of time series. Visual active learning can assist educators develop on-line instructional visualisations and replenish this multimodal method to remain more focused on their instructional objectives (Wen & Wand, 2020).

Learning through visualization is beneficial

According to Gavrilova et al. (2017), the data visualization literature is dispersed, and the authors emphasize the importance of expanding our current understanding in this particular area of study. Most study into the classification or combination of approaches to visualization has been on information visualization (van Biljon & Renaud, 2015; Eppler & Burkhard, 2004, 2007; Eppler & Pfister, 2014). There were just a few studies on the advantages and disadvantages of knowledge visualisation that show that this is an intriguing field for future research (Bresciani & Eppler, 2015; Eppler & Platts, 2009; Pfister & Eppler, 2012). Visualization is advantageous because it enables the explicit representation of scientific ideas through static images or animations (Rundgren et al., 2012). On the other hand, dynamic visualization can help students grasp abstract concepts about molecular processes more effectively than static diagrams. Rundgren and Tibell (2010) investigated students' perceptions of a static image and an animation depicting cell membrane transfer. Additionally, these findings indicate that animations are more effective at assisting students in comprehending the complex processes of transport through the cell membrane. Ryoo and Linn (2012) discovered that dynamic visualizations could improve 7th graders' comprehension of photosynthesis compared to static illustrations. In science education, visualization research has established a connection between learners' spatial abilities and prior knowledge and their use of ER in science learning (Wu, Lin, & Hsu, 2013). Although visualization necessitates spatial ability, it can be a valuable tool for improving learners' spatial abilities. Externalizing concepts through visual representations offers a shared reference point' for strengthening communication abilities, according to (Rundgren et al., 2010). According to Velázquez-Marcano et al. (2004), students can more accurately predict the result of absorption and dispersion problems when they integrate molecular-level visualizations with video recordings of macroscopic events. According to (Höffler, 2010), spatial aptitude is an important factor to consider when learning through visuals, but it can be compensated for by the latter's features. Dynamic visualizations outperform static visuals, and three-dimensional visualizations outperform two-dimensional visualizations for students with limited spatial abilities. In a more recent investigation, Höffler and Leutner (2011) discovered that spatial ability is also required for the production of mental alterations or spatial adaptations of a group of static images. Students with limited spatial abilities learned less from four static instances than students with outstanding spatial abilities, however animation learning was independent by spatial ability. As a result, research on the significance of spatial aptitude in learning from static images is still inconsistent. It is necessary to interconnect several scenes and mentally manage various static characteristics in order to generate a dynamic conceptualization from a series of static images; a highly developed spatial skill can assist in this capacity. As a counter-argument, because of its transitivity, animations might be difficult to interpret for learners with limited spatial abilities.

As a result, this research contrasts learning from static images to learning from an instructional animation. To that end, the purpose of this study is to address the following questions:

1. *When provided dynamic visualizations rather than static visuals, is the experimental group statistically more successful than the control group at visualizing mechanical concepts?*
2. *What impact does animation have on students' comprehension of mechanics concepts?*

Theoretical overview

Students' understanding of concepts in mechanics

Numerous studies have examined students' comprehension of physics concepts. Van Heuvelen (1991) claimed that several experiments in physics education demonstrated that straightforward teaching failed to accomplish the objectives. He clarified that students exit their courses with roughly the same status as they entered. Since the 1970's, considerable educational research has concentrated on students' attitudes toward scientific principles (Hestenes et al., 1992; Halloun & Hestenes, 1985; Bayraktar, 2009). "Misconceptions" or "alternative conceptions" are terms used to describe them. Some academics feel that learners' misunderstandings are more set, theory-like ideas, while others regard them as varied ways of looking at things that are acceptable in different settings.

The following are some of the most common misunderstandings about mechanics:

- A common believe is that heavier objects fall faster than lighter ones (Bayraktar, 2009; Hestenes et al., 1992; McDermott, 1984).
- In order for a body to remain in motion, it must be pushed by a force. As a result, students feel it should be a force that moves in the same direction as the motion (Bayraktar, 2009; McDermott, 1984).
- More active objects are assumed to exert more force (Bayraktar, 2009).

Force Concept Inventory (FCI)

The Force Concept Inventory (FCI) (Hestenes, 1992) is a one-of-a-kind test that evaluates student understanding of Newtonian physics' most basic principles. It has a number of functions, the most significant of which is to assess the effectiveness of instruction. The FCI is probably the most commonly used instrument in physics education today for this reason. The inventory contains 30 multiple-choice questions, each with a minimum amount of mathematical content. There is a considerable amount of research demonstrating that certain topics within the FCI are discriminatory against women, with a few exceptions being discriminatory against men. Scott et al. (2012) and Semak et al. (2017) have often combined variables in previous research, raising the risk that certain factors are found as a result of problem-specific biases. Additionally, gender inequality has been extensively documented in FCI accomplishments (Dockter & Heller, 2008), and can be seen both in general and in specific items (Henderson et al., 2018). According to

Traxler et al. (2018) eight FCI criteria can explain the gender difference, six of which have girls that overtake men and two show the opposites patterns. They found out that the gender gap was considerably reduced by removing these 8 variables from their investigation. In contrast to Madsen et al. (2013), who found that a range of variables produce sex imbalance, Henderson et al. (2019) noticed that the difference between women and men was impacted by a mix of causes, meaning that the way Newtonian mechanics is taught cannot be removed easily. The origins of the gender disparity in FCI achievement remain unexplained, according to Madsen et al. (2013). In order to determine the students' preconceptions, Scott and Schumayer (2017) looked for imprecise replies to FCI questions. They thought that there were links between the FCI parts and that they had been analyzed by the Exploratory Factor. They found that a large percentage of pupils (N = 2109) while delivering wrong FCI answers, had consistent non-Newtonian world conceptions. They found that a large percentage of students (N = 2109) had consistent non-Newtonian perspectives and inaccurate answers to the FCI. Using a network evaluation approach, Scott and Schumayer (2018) analyzed links between the cohort's erroneous FCI responses. Students commonly misinterpreted Newton's First Law, according to the study's authors, which they regarded as a fundamental hurdle to learners developing a Newtonian perspective. Eaton and Willoughby (2018) have used an FCI response dataset of 20,882 students to confirm these results.

From static to animated instructional presentations

Dynamic visualizations such as animations or graphics are, as reported by Schnotz and Lowe (2008), constantly changing representations and indicating a constant motion process, but static visualizations describe just particular states arising from that movement. Several researchers find that dynamic animations are better than static ones, while others conclude that static images are superior (Imhof et al., 2012; Lowe et al., 2011; Mayer et al., 2005). Furthermore, no significant differences have been seen between instructional dynamic and static images (Boucheix & Schneider, 2009; Höffler et al., 2010). Although it is evident that dynamic versus static representations offers considerably different learning outcomes, publications have not consistently preferred one over the other. Given the conflicting results, some researchers have proposed investigating when and why dynamic versus static representations can be better for learning (Bétrancourt, 2005; Schnotz & Lowe, 2008). Animation, in contrast to the static display, has a number of benefits and drawbacks. Animation's capacity to openly express the spatial features of the pieces is one of its most obvious advantages (Bétrancourt et al., 2001). Schnotz and colleagues (Schnotz & Rasch, 2005; Schnotz, 2005) emphasized the potential impact of animation on learning. The continuity of animation, which needs to be handled by definition in real time, can make it impossible to understand any fundamental changes in contemporary times (Bétrancourt et al., 2001). In addition, before further processing, vast quantities of transient animation data must be processed and stored in working memory. This results in cognitive overload, inaccessibility of knowledge and task failure (Jones & Scaife, 2000; Mayer & Moreno, 2002). According to multiple researchers, dynamic visualizations surpassed static sequential visualizations but not static simultaneous visualizations (Boucheix & Schneider, 2009; Imhof et al., 2012). Dynamic visuals have a beneficial influence on direct animation but a bad influence on short term effects, whereas static visualizations have a bad influence on mental animation but a favorable permanent effect (Castro et al., 2018). Because learners are spared of the burden of mentally animating a system's spatial changes, dynamic visualizations can minimize processing demands, particularly superfluous cognitive burden (Hegarty & Kriz, 2008). On the other side, dynamic visualizations may have the drawback of being transitory. Dynamic visualization does not contain permanent information but transitory data because of time-limiting work memory (Ainsworth & VanLabeke, 2004), which might enhance cognitive user loading and impede learning (van Merriénboer & Sweller, 2005).

Methodology

The purpose of this quasi-experimental study is to determine the effect of contrasting static and dynamic scenarios on the evaluation of mechanics and physics concepts. The study utilized a pretest/posttest design and divided individuals into two groups: experimental and control. We wanted to see if dynamic animation could provide more insight into students' comprehension than traditional pencil and paper examinations.

Dynamic visualization creation

The Force Concept Inverntory (FCI) (Hestenes et al., 1992) was used in this study to assess the students' conceptual comprehension. The Force Concept Inventory (FCI) is a multiple-choice conceptual evaluation administered using a pencil and paper. Several questions on the inventory questionnaire were rewritten and modified to include dynamic animation in place of static images and explanations of motion. To transform each FCI question into a dynamic animation, a 2D model was made as simple as possible with the intent of pupils comprehending the problem's motion. Blender (http://www.blender.org), a free open-source 3D rendering software, was used to produce each dynamic animation. A web-based platform was chosen to be the most efficient method for teachers to collect data and students to simply play the dynamic animation. Students were sent the dynamic animation via *Google Forms*, and they could well have accessed the video via a computer or a mobile phone. Figure 1 depicts a screenshot of one of the questions' dynamic animation in *Google Forms*.

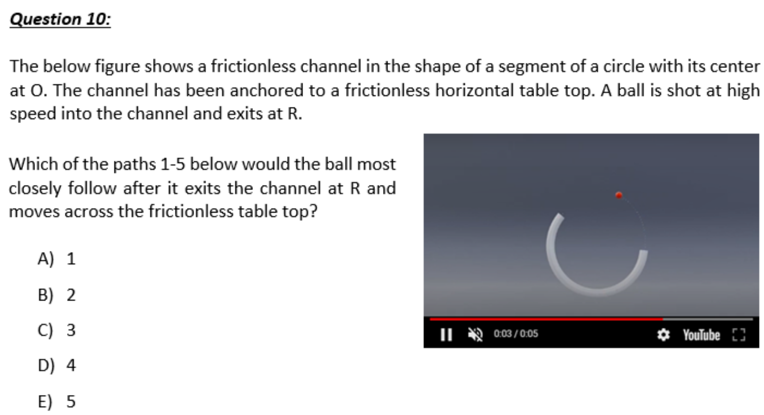


Figure 1. A dynamic animation presents the situation of the problem created in Blender.

Data collection

The study enrolled 60 eleventh-grade students from two science classrooms at a public high school in Albania, each taught by the same teacher. Participants were randomly selected and randomly assigned to one of the two groups: experimental or controlled. All who participated in the research were given an accurate description of the study, and their oral consent was obtained. Before the teacher's explanation, students in the controlled group, which consisted of *30 students* (14 males and 16 females), were given a hybrid test of the FCI composed of 10 questions followed by static images. On the other hand, the experimental group of *30 students* (18 males and 12 females) received the same test but animated videos instead of static images. To determine if animated videos significantly impact students' mental comprehension than static images, both groups participated in a post-test on static images.

Pre-test

A hybrid FCI paper test was given to students in the controlled group. The test consisted of ten multiple-choice questions accompanied by static images depicting the problem's condition. The test was rated on a ten-point scale, with each question worth one point. The purpose of this test was to assess students' understanding of mechanics concepts prior to the teacher's explanation. Due to the fact that the FCI was not intended to be converted to animation, achieving this conversion was sometimes challenging. For these purposes, several minor modifications have been made to the queries, including the inclusion of static images where no image was available in the FCI inventory. Such modifications will be discussed below.

Question 1

In this question, two objects were thrown from a certain height, and students were asked to estimate the time required for the objects to reach the ground. Since animating a case like this provides students with the answers, the question was modified. The question was changed to when two objects of the same size are thrown from a certain height (without considering air resistance) which of the objects will reach first the ground. Additionally, a static image was generated to assist students in conceptualizing the scenario.

Question 2

Rather than having two objects rolling in a horizontal table, this query now uses a single object and asks for the parameters concerning the final position of the object. The static image was generated to assist students in conceptualizing the scenario.

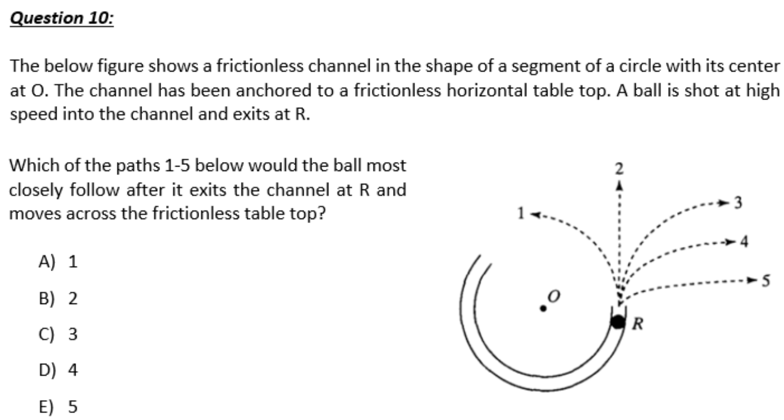
Question 12

Two other problems were drawn from this one, all of which concern the same fundamental concepts. Three balls were launched from the ground at varying angles by cannon, and students were asked which had the longest travel time based on a static given picture.

Question 14

Students were asked a related question about the outcome graph of the velocity of a tossed ball in vertical motion.

During the paper exam, students were assessed on the principle of forces acting on all surfaces regardless of air resistance. A static image as shown in Figure 2 was used to display the event.



Question 10:

The below figure shows a frictionless channel in the shape of a segment of a circle with its center at O. The channel has been anchored to a frictionless horizontal table top. A ball is shot at high speed into the channel and exits at R.

Which of the paths 1-5 below would the ball most closely follow after it exits the channel at R and moves across the frictionless table top?

A) 1

B) 2

C) 3

D) 4

E) 5

Figure 2. A static picture accompanies a problem from the pre-test. Adapted from the force concept inventory by Hestenes et al. 1992.

The experimental group, on the other hand, received the same ten multiple-choice questions but with animated videos instead of static pictures. Since it is impossible to have a paper-based evaluation for an animation, the students in this group were given an internet-based test. The test was conducted using *Google Forms*, in which students were able to play the video and view a dynamic simulation of the problem's condition.

Post-test

Following completion of the pre-test, students from both groups were informed of their results and provided with feedback. After the teacher explained the chapter on forces and Newton's law, the post-test was administered to both groups. The post-test consisted of twenty multiple-choice questions of which ten questions were taken from FCI inventory and ten questions from IB exam questions. We chose this distribution to determine if the outcomes are different when evaluating only FCI questions versus analyzing scores from both FCI and IB exam questions. The test was rated on a twenty-point scale, with each question worth one point. For practical purposes, the test was administered through *Google Forms,* and some questions were accompanied by a static image of the situation, while others were not accompanied by an image at all.

Method of data analysis

The t-test of independent and dependent samples was used to analyze the data acquired. The research questions made for the study were tested using the t-test of independent samples at $p < 0.05$ probability level.

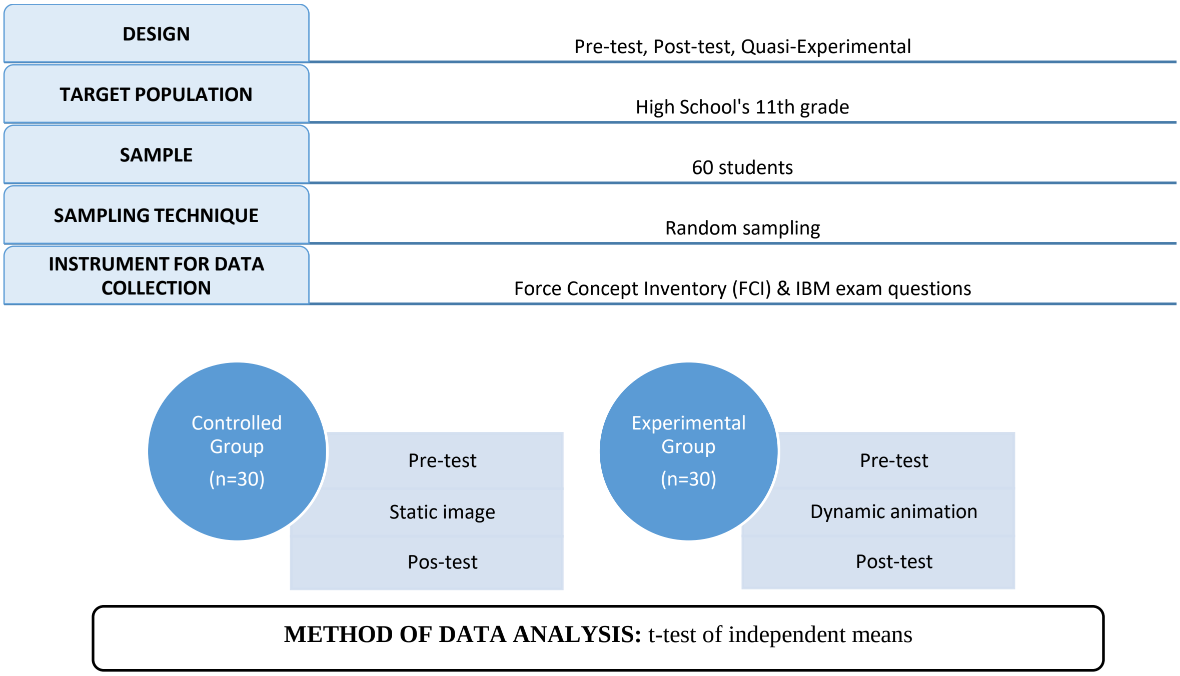


Figure 3. Schematic representation of the method

Results

The findings of this study are divided into three comparisons, addressing two research questions. Two independent t-tests were conducted between the two groups in the first and second sections, comparing pre-and post-test scores between the control and experimental groups. A comparison of the differential scores between the two groups (post-test and pre-test) was also performed.. Table 1 summarizes the data by presenting the students' matched pre-and post-test outcomes.

Table 1.

The results of the pre-post testing, and the disparities between the two study groups.

	Group	*Mean ± SD*	*SE*	*t*	*p*
Pre-test	Control	5.77 ± 1.69	0.31	**-1.94746**	**0.028163**
	Experimental	6.53 ± 1.33	0.24		
Post-test	Control	13.07 ± 3.36	0.61	**3.67645**	**0.000259**
	Experimental	15.77 ± 2.17	0.40		
Difference	Control	7.3 ± 3.92	0.71	**2.23385**	**0.014682**
	Experimental	9.24 ± 2.66	0.48		

*$p < 0.05$. SD: Standard deviation, SE: Standard error

RQ. 1: *How effective are dynamic representations compared to static images when it comes to understanding force concepts.*

In the current study, the t-test with an initial alpha value of.05 was used to assess both the experimental and control groups' achievement during the pre-test. Because one condition was performed by the experimental group (using dynamic visualizations) and the other condition was performed by the control group (using static images), an independent-means t-test design was adopted. The findings revealed that the experimental and control group had a discernible difference in pre-and post-test scores. Students in the experimental group who were exposed to dynamic visualization scored statistically considerably higher than students in the control group who were only exposed to static visuals. The 30 participants who received the dynamic visualizations intervention (M = 6.53, SD =1.33) compared to the 30 participants in the control group (M = 5.77, SD =1.77) demonstrated significantly better peak flow scores, the t(60) = 1.94, p = .028. The result is significant at $p < .05$. Later on, both groups were examined using an independent-means t-test design on post-test outcomes following the intervention of dynamic visualizations. The t-test with an initial alpha value of .05 was used to assess both the experimental and control group’s achievement on the post-test. The 30 participants who got the dynamic visualization intervention on the pre-test performed much better on the post-test than the control group, who got just static images on both pre-and post-tests. The results demonstrated a statistically significant difference in mean scores between the experimental (M = 15.77, SD =2.17) and controlled group (M = 13.07, SD =3.36), the t(60) = 3.67, p = .000259. The result is significant at $p < .05$. Furthermore, the differences in score between the experimental and control group in pre-test and post-test were compared. The mean achievement scores of the experimental group (M = 9.24, SD =2.66) and control group (M = 7.3, SD =3.92) for the pre-test and post-test are shown in Table 1. The result is significant at $p < .05$ with a respective t(60) = 2.23, p = .014.

RQ. 2: *What impact does animation have on students' comprehension of mechanics concepts?*

Three-quarters of the questions showed a statistically significant difference when the distribution of item responses was compared between those who saw the animation and those who saw the static version. Five of these items had a significant variation in the distribution of responses in terms of the correct answer choice, as shown in Table 2.

Table 2.

Results for questions that identify significant performance discrepancies.

	% Correct (N=30)	
Question	***Animation***	***Static***
1	93.3%	66%
4	80%	6.7%
5	3.4%	83%
6	83%	50%
10	90%	60%

There were four questions (1, 4, 6, and 10) on which the animated group outperformed the static group by a substantial margin, and one question (5) on which the static group outperformed the animated group. Only seven of the ten questions had important information displayed during the animation out of a total of ten. In order to successfully answer such questions, pupils were required to watch the animation. All relevant information was provided in the problem statement for the remaining components, making the animation unnecessary. It's worth noting that each of the five questions in Table 2 that were deemed relevant featured animations conveying vital information. Furthermore, animation can sometimes guide students to the correct answer while other times it does not.

Discussion and conclusion

This study examined whether dynamic animations boost conceptual understanding in students when compared to static visuals. The experimental and control groups performed significantly differently before and after the test, with the experimental group surpassing the control group both before and after the test. These findings are consistent with those of Berney and Bétrancourt (2016), who discovered that animations boosted student learning more than static graphics. Höffler and Leutner (2007), Berney and Bétrancourt (2016), and Castro-Alonso et al. (2019) discovered only a tiny influence of dynamic visualization on the educational effect, which may explain why they were widely utilized and demonstrated just a minor effect for both animations and films. On the other hand, Kühl et al. (2019) and Tversky et al. (2002) found that animations provide information advantages over static images, assuming the changes depicted are relevant to the study and how they develop in time. While animations clearly depict changes, static images just hint at them (Jenkinson, 2017). As a result, whereas learners can perceive changes directly while learning from animations, they must make assumptions about changes when learning from static images, which is a difficult and susceptible approach (Hegarty et al., 2003). Consequently, animations can be better than static visuals, if the changes displayed and how they develop in time are relevant to learning. While video reflect the kinematics of real-world objects, animations become increasingly realistic as better animation techniques and resources become available (Parent, 2012). Another element of our findings worth noting is the compensating effect of animation over static visuals in five of the questions directly related to force concepts. Our findings indicate that including a visual environment improves learners' conceptual knowledge and reasoning skills, same as with the prior studies (Barak & Dori, 2005; Kaberman & Dori, 2009; Garcia et al. 2007). As this is necessary to create logical relations, students exposed to dynamic questions have fewer misunderstandings than their peers in the control group. Animation may help in understanding learning materials and can also be utilized as a substitute for challenging cognitive processes such as imagination and creativity by permitting the building of cognitive models of concepts and phenomena. Other research suggests that the use of animations and images improves conceptual comprehension (Barak & Dori, 2005), learning outcomes for students (Dori et al. 2003; Dori & Belcher, 2005), and desire to interact throughout the learning (Barak et al. 2011).

Limitations

Different factors, such as teaching approach, gender, cultural orientation, or geography, may limit the conclusions of this study. Due to the current situation with Coronavirus (COVID-19), instruction was transmitted online, making sample collection even more difficult and sometimes inaccurate than it would have been if it had been done face to face with students.

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In memory of my beloved uncle, Thoma

Author's declaration

I hereby declare that I have written this thesis independently and that all contributions of other authors and supporters have been referenced. The thesis has been written in accordance with the requirements for graduation theses of the Institute of Education of the University of Tartu and is in compliance with good academic practices.

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Appendices

Appendix A: Pre-test questionnaires

Ten multiple-choice questions accompanied by static images depicting the problem's circumstance were administered to the control group in a hybrid FCI (Hestenes et al., 1992) paper test.

Male ☐ *Female* ☐ Age: _______

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. Which of the ball will reach first the ground?

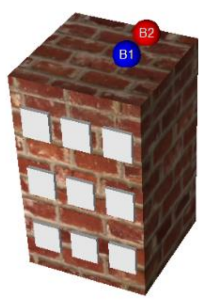
   a) ball (B1) with the weight twice as ball (B2)

   b) ball (B2) with the weight half as ball (B1)

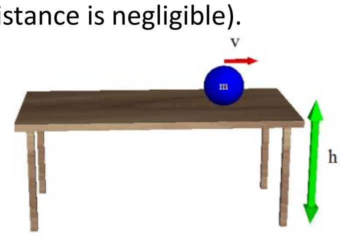
   c) both balls (B1) and (B2) at the same time

   d) none of the balls will reach the ground

   e) ball (B1) with the weight triple as ball (B3)



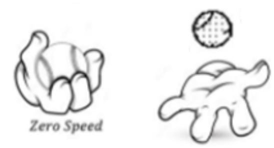
2. A ball of mass m is projected horizontally with speed v from a height h above the floor (air resistance is negligible).



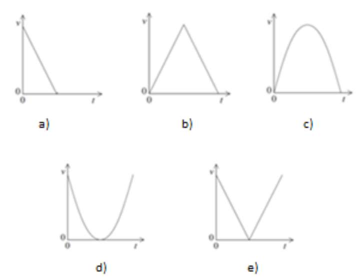
   The horizontal distance travelled by the ball to the point where it lands on the floor depends on:

   a) v and h only.
   b) m, h and v.
   c) h and m only.
   d) v and m only.
   e) only m.

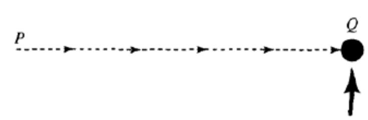
3. An object is thrown upwards leaving the thrower's hand at time t=0.



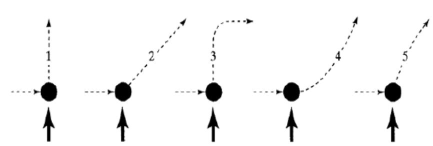
   Which graph shows how speed v varies with t as the object rises and falls?



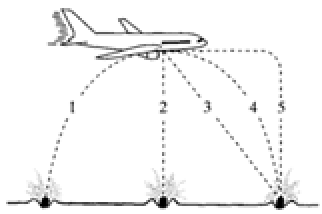
4. The figure depicts a hockey puck sliding with constant speed v_0 in a straight line from point to P to point Q on a frictionless horizontal surface. When the puck reaches point Q, it receives a swift horizontal kick in the direction of the heavy paint arrow.



   Which of the paths 1-5 below would the puck most closely follow after receiving the kick?

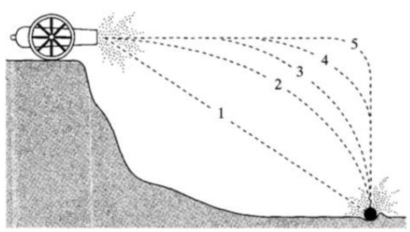


5. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

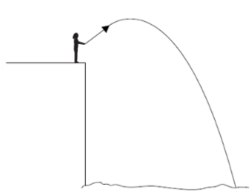


As observed by a person standing on the ground and viewing the plane as in the figure below, which of the paths 1-5 would the bowling ball most closely follow after leaving the airplane?

6. A ball is fired by cannon from the top of a cliff as shown below. Which of the paths 1-5 would the cannon ball most likely follow?

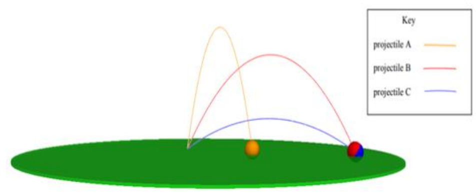


7. A stone dropped from the roof of a single-story building to the surface of Earth.



a) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
b) Speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to Earth.
c) Speeds up because of an almost constant force of gravity acting upon it.
d) falls because of the natural tendency of all objects to rest on the surface of Earth
e) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

8. Three projectiles A, B and C are all launched from the same position at the same time and reach the same maximum height. Their trajectories are shown in the diagram above.

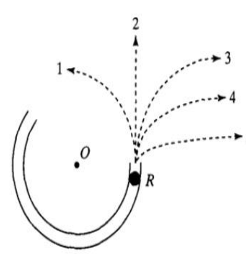


Which projectile has the greatest flight time?
a) Projectile A.
b) Projectile B.
c) Projectile C.
d) Projectile A and B.
e) They are all the same.

9. From the previous exercise, which projectile was launched at the greatest speed?
a) Projectile A.
b) Projectile B.
c) Projectile C.
d) Projectile A and B.
e) They are all the same.

10. The below figure shows a frictionless channel in the shape of a segment of a circle with its center at O. The channel has been anchored to a frictionless horizontal table top. A ball is shoot at high speed into the channel and exits at R.

Which of the paths 1-5 would the ball most closely follow after it exits the channel at R and moves across the frictionless table



Pre-test questionnaire (experimental group)

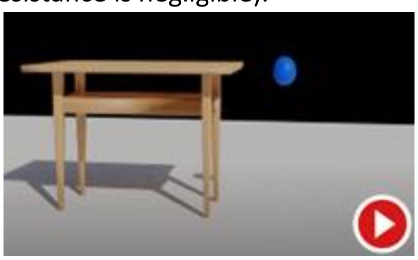
Ten multiple-choice questions accompanied by dynamic visuals showing the problem's situation in a hybrid FCI (Hestenes et al., 1992) test.

Male ☐ *Female* ☐ Age: _______

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. Which of the ball will reach first the ground?

   a) ball (B1) with the weight twice as ball (B2)
   b) ball (B2) with the weight half as ball (B1)
   c) both balls (B1) and (B2) at the same time
   d) none of the balls will reach the ground
   e) ball (B1) with the weight triple as ball (B3)

2. A ball of mass m is projected horizontally with speed v from a height h above the floor (air resistance is negligible).

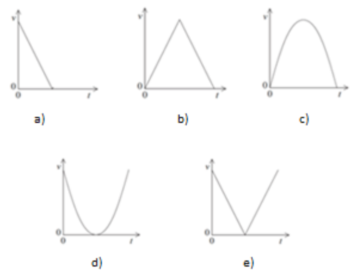


   The horizontal distance travelled by the ball to the point where it lands on the floor depends on:

   a) v and h only.
   b) m, h and v.
   c) h and m only.
   d) v and m only.
   e) only m.

3. An object is thrown upwards leaving the thrower's hand at time t=0.

   Which graph shows how speed v varies with t as the object rises and falls?

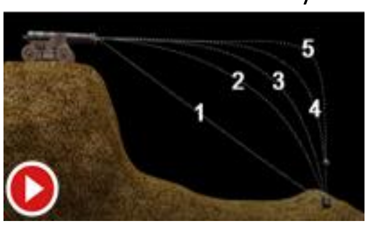


4. A hockey puck sliding with constant speed v_0 in a straight line from point to P to point Q on a frictionless horizontal surface. When the puck reaches point Q, it receives a swift horizontal kick in the direction of the heavy paint arrow. Which of the paths 1-5 shown in the video would the puck most closely follow after receiving the kick?

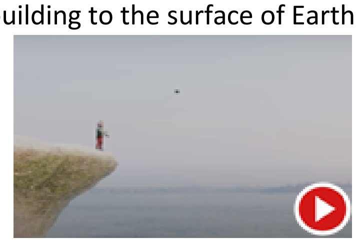
5. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

As observed by a person standing on the ground and viewing the plane as in the figure below, which of the paths 1-5 would the bowling ball most closely follow after leaving the airplane?

6. A ball is fired by cannon from the top of a cliff as shown below. Which of the paths 1-5 would the cannon ball most likely follow?

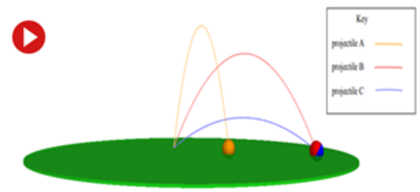


7. A stone dropped from the roof of a single-story building to the surface of Earth.



a) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
b) Speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to Earth.
c) Speeds up because of an almost constant force of gravity acting upon it.
d) falls because of the natural tendency of all objects to rest on the surface of Earth
e) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

8. Three projectiles A, B and C are all launched from the same position at the same time and reach the same maximum height. Their trajectories are shown in the diagram above.



Which projectile has the greatest flight time?
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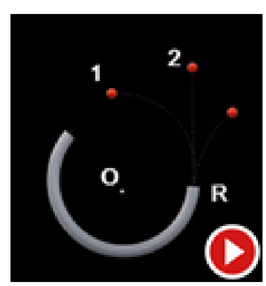
c) Projectile C.
d) Projectile A and B.
e) They are all the same.

9. From the previous exercise, which projectile was launched at the greatest speed?
a) Projectile A.
b) Projectile B.
c) Projectile C.
d) Projectile A and B.
e) They are all the same.

10. The video below shows a frictionless channel in the shape of a segment of a circle with its center at O. The channel has been anchored to a frictionless horizontal table top. A ball is shoot at high speed into the channel and exits at R.

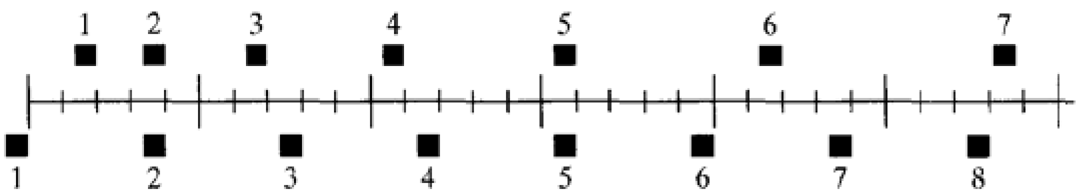
Which of the paths 1-5 would the ball most closely follow after it exits the channel at R and moves across the frictionless table top?



Appendix B: Post-test questionnaire (experimental & control group)

The post-test comprised of twenty multiple-choice questions, 10 from the FCI inventory (Hestenes et al., 1992) and 10 from the IB exam questions (https://questionbank.ibo.org/).

1. The positions of two blocks at successive 0.20-s time intervals are represented by the numbered squares in the following figure. The blocks are moving toward the right.

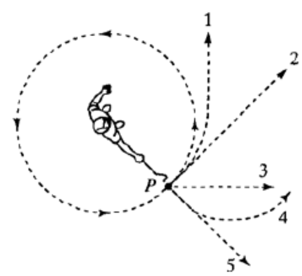


Do the blocks ever have the same speed?

a) No.
b) Yes, at instant 2.
c) Yes, at instant 5.
d) Yes at instant 2 and 5.
e) Yes, at some time during the interval 3 to 4

2. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the figure below. At point P, the string suddenly breaks near the ball. If these events are observed from directly above, which of the paths 1-5 below would the ball most closely follow after the string breaks?

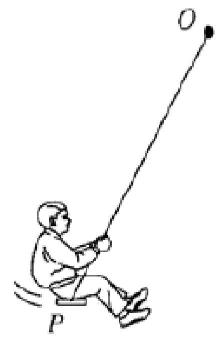
a) 1
b) 2
c) 3
d) 4
e) 5



3. Two metal balls are the same size but one weights twice as much as the other. The balls are dropped from the roof of a single story building at the same instant. The time it takes the balls to reach the ground below will be:

a) About half as long for the heavier ball as for the lighter one.
b) About half as long for the light ball as for the heavier one.
c) About the same for both balls.
d) Considerably less for the heavier ball, but not necessarily half as long.
e) Considerably less for the light ball, but necessarily half as long.

4. The following figure shows a boy swinging, starting at a point higher than P. Consider the following distinct forces:



A. a downward force of gravity

B. a force exerted by the rope pointing from P to O.

C. a force in the direction of the boy's motion.

D. a force pointing from O to P.

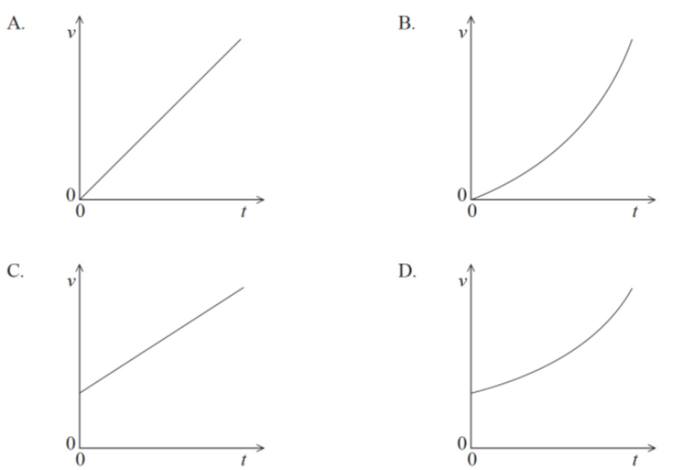
Which of the above forces is (are) acting on the boy when he is at position P?

a) A only
b) A and B
c) A,B and C
d) A,C and D
e) No force at all

5. If a moving object is subject to a constant force, which of the following can be correctly deduced from Newton's first law?

a) The object continues to move with a changing velocity.
b) The object continues to move with a constant velocity.
c) The object continues to move with a changing direction.
d) The object continues to move in the same direction.
e) The object moves and then stops suddenly.

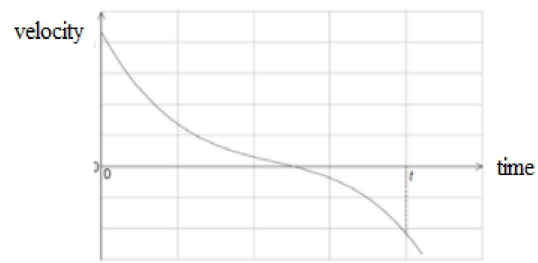
6. A car accelerates from rest. The acceleration increases with time. Which graph shows the variation with time t of the speed v of the car?



7. An object falls from a height (air resistance is not negligible). What is the acceleration of the object at the beginning of the movement?

a) zero
b) it will increase
c) it will decrease
d) constant
e) none of the given answers

8. The graph below shows the change over time of the speed of a truck of mass M. What can be read from the graph?

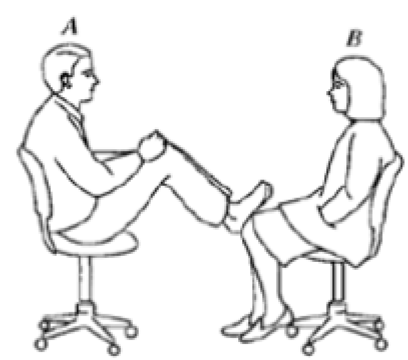


a) The truck is always accelerating.
b) The truck is always in motion.
c) The truck always moves in one direction.
d) The displacement of the truck after time t is zero.
e) The truck is at rest.

9. A tennis ball falls vertically a small distance in the air. The speed of the tennis ball will:

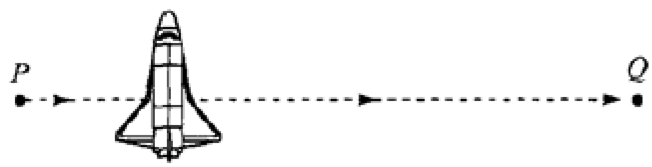
a) increase.
b) decrease.
c) increases and then decreases.
d) decreases and then increases.
e) none of the answers given.

10. In the following figure, student A has a mass of 75 kg and student B has a mass of 57 kg. They sit in identical office chairs facing each other. Student A pushes with his feet, causing both chairs to move. Which student exerts the greatest force while pushing?

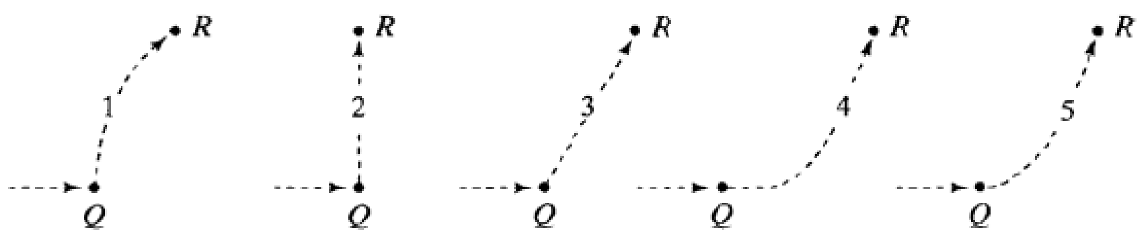


a) No student exerts force on another.it will increase
b) Student A exerts a force on student B, but does not exert any force on A.
c) Each student exerts a force on the other, but B exerts a greater force.
d) Each student exerts a force on the other, but A exerts greater force.
e) Each student exercises the same force on the other.

11. A spaceship drifts sideways in outer space from point P to point Q as shown below. The spaceship is subject to no outside forces. Starting at position Q, the spaceships engine is turned on and produces a constant thrust (force on the spaceship) at right angles to the line PQ. The constant thrust is maintained until the spaceship reaches a point R in space.



Which of the paths 1-5 below best represents the path of the spaceship between points Q and R?

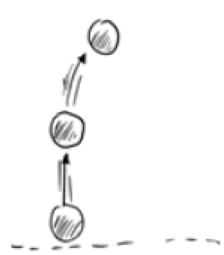


12. As the spaceship moves from points Q to point R its speed is:

a) Constant
b) Continuously increasing.
c) Continuously decreasing
d) Increasing for a while and constant thereafter
e) Constant for a while and decreasing thereafter

13. A rock is thrown vertically above the surface of the Earth. Which of the following magnitudes will not become zero while the stone is in the air?

a) Speed
b) Force
c) Angle
d) Acceleration
e) Momentum



14. Two objects are dropped from a bridge, an interval of 1.0 s apart. Air resistance is negligible. During the time that both objects continue to fall, their separation

a) increases.
b) decreases..
c) stays constant.
d) increases at first, but then stays constant.
e) decreases at first, but then stays constant.

15. An empty office char is at rest on a floor. Consider the following forces:

A) a downward force of gravity.
B) an upward force exerted by the floor
C) a net downward force exerted by the air.

Which of the forces is (are) acting on the office chair?

a) A only
b) A and B
c) B and C
d) A,B and C
e) None of the forces. (Since the chair is at rest, there are no forces acting upon it.)

16. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are)**:**

a) A downward force of gravity along with a steadily decreasing upward force.
b) A steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the ball gets closer to Earth.
c) An almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only an almost constant downward force of gravity.
d) An almost constant downward force of gravity only.
e) None of the above. The ball falls back to the ground because of its natural tendency to rest on the surface of the Earth.

17. A stone dropped from the roof of a single-story building to the surface of Earth

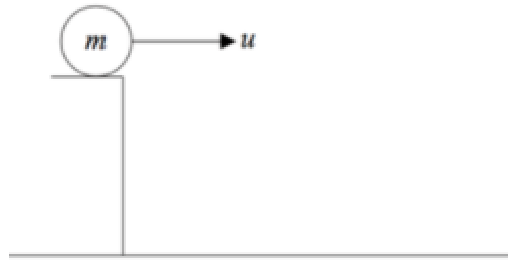
a) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter
b) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to Earth
c) speeds up because of an almost constant force of gravity acting upon it.
d) falls because of the natural tendency of all objects to rest on the surface of Earth
e) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

18. Ball A is dropped from the top of a building. One second later, ball B is dropped from the same building. Neglect air resistance. As time progresses, the difference in their speeds

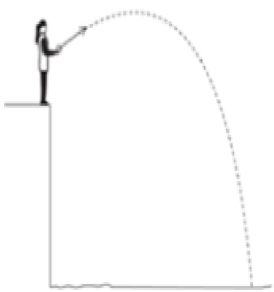
a) increases.
b) remains constant.
c) decreases.
d) cannot be determined from the information given.
e) is zero.

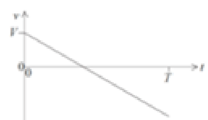
19. A ball of mass (m) is thrown horizontally from a height with initial velocity (u) (air resistance is negligible). Which of the sizes will affect the horizontal distance traveled?

a) Only the mass (m)
b) Initial velocity (u)
c) Mass (m) and velocity (u)
d) Neither mass (m) nor velocity (u)
e) None of the given alternatives

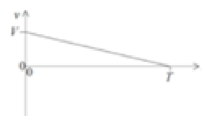


20. A ball is thrown from the top of a rock. The initial magnitude of the ball velocity at time t = 0 is (v). The ball hits the sea at time t = T (Air resistance is negligible) .Which graph shows how the vertical component of the velocity v of the ball changes with t as it falls into the sea?

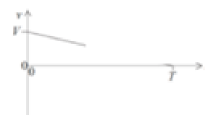




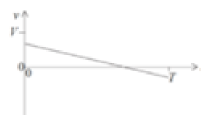
a)



b)



c)



d)

e)

Appendix C: Creation of the dynamic visualizations in Blender

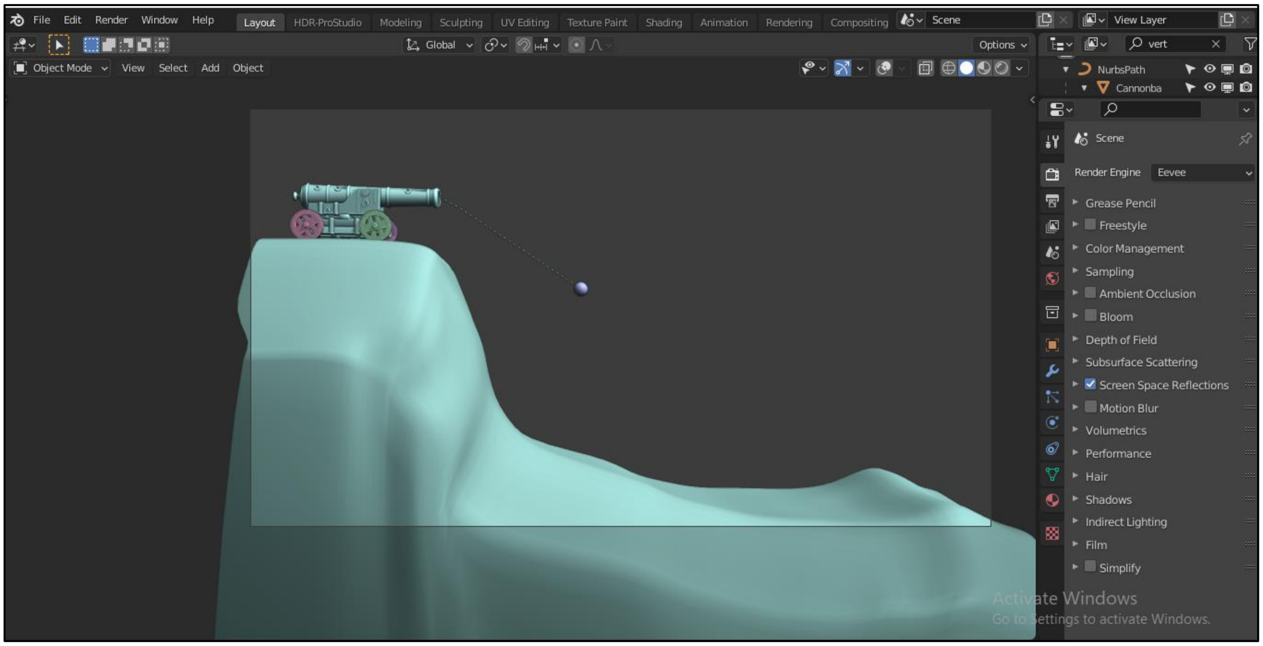


Figure 6. Creation of question 6 in Blender (http://www.blender.org).

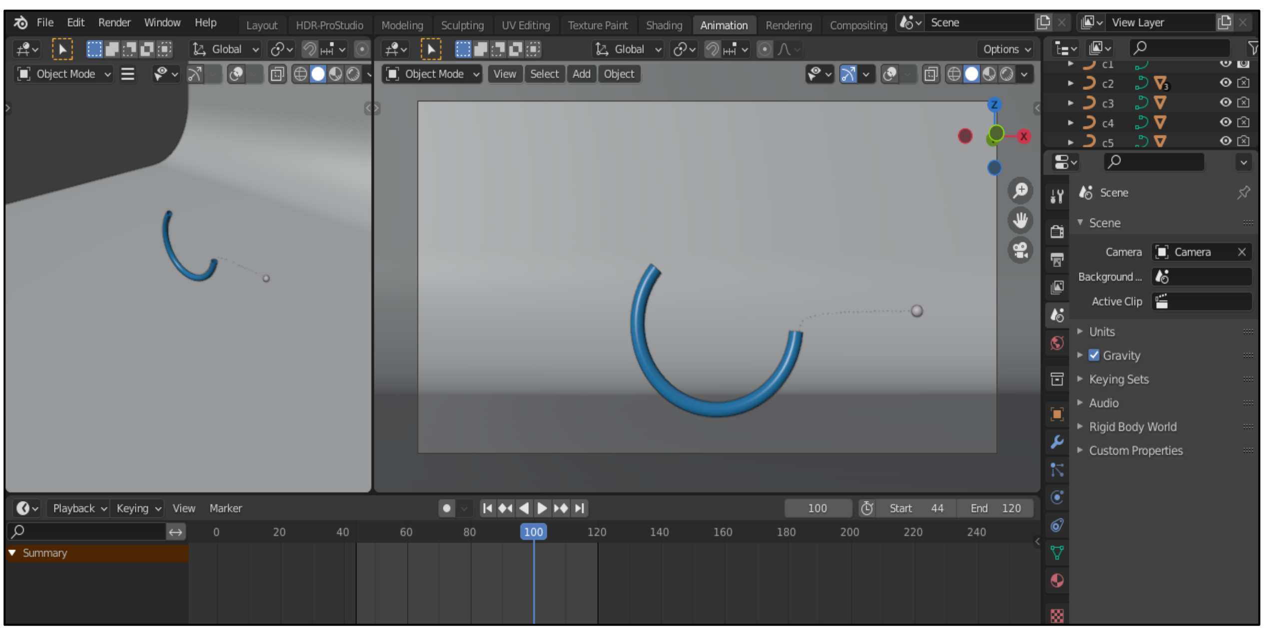


Figure 7. Creation of question 10 in Blender (http://www.blender.org).