European Journal of Education Studies
ISSN: 2501 - 1111
ISSN-L: 2501 - 1111
Available on-line at: www.oapub.org/edu

doi: 10.5281/zenodo.1241479

Volume 4 | Issue 6 | 2018

IMPACT OF VISUALIZATION ON TEACHING AND LEARNING PHYSICS AT SECONDARY SCHOOL LEVEL

Madawala Liyanage Shanaka Piyatissa[i],
Md Gapar Md Johar,
Arun Kumar Tarofder
Graduate School of Management,
Management and Science University,
Shah Alam, Malaysia

Abstract:
There involves an overt component of visualization in physics and helping students to visualize the needed areas in physics using suitable external representations is a way to strengthen students' familiarity with the visualization aspect embedded therein. This study is a field experiment made around evaluating the effectiveness of emphasizing the visualization aspect in two secondary school physics lessons, kinematics and Newton's laws of motion, by way of utilizing the visual mode of external representation in the form of computer aided learning materials such as suitable diagrams shown through computer screen, video clips, animations and simulations. A pre-test and post-test experimental design was used in the study by getting the participation of 184 secondary school students (grade 10) in three government schools in Sri Lanka. A physics test capable of assessing students' attainment in visualizing the identified areas in the two lessons called Visualization Related Physics Test (VRPT) which is a lesson specific assessment tool was developed. The VRPT is a reliable instrument which showed acceptable Cronbach's alpha value of 0.711. The experimental group has shown an overall gain of about 14% at post-test administration of VRPT compared to the pre-test administration whereas the corresponding gain in the control group was about 1%. The students' view on the approach was evaluated using a questionnaire and their views were favorable. It is concluded in this study that emphasizing the visualization aspect at classroom teaching by paying a deliberate attention can be used as a remedial measure for improving students' physics performance.

Keywords: visualization, representations, model, physics education, assessment

[i] Correspondence: email shanakapiyatissa77@gmail.com

1. Introduction

Though there are slightly differing definitions available at present for the term visualization, in very simple terms, visualization can be taken as any type of representation designed to make an abstract scientific concept visible (Rapp & Kurby, 2008; Uttal & O'Doherty, 2008). Representation in this context means creating one structure that stands for something else. Representations are two-fold: external representations and internal representations (Gilbert, 2005). The students experience the external representations by way of modes of (external) representations (Gilbert, 2005) used by the teacher at classroom teaching, namely, the material/the concrete mode (physical models or practical set ups), the verbal mode (written and spoken language), the symbolic mode (standard notations and formulae), the visual mode (diagrams, graphics, graphs, videos, animations, simulations, etc.), and the gestural mode (gestural expressions). With relevance to the external representations, the students build internal representations which are also called visualizations, mental images or visual-perceptions (Gilbert, 2005; Gilbert, 2010) in science education. Also, the temporal/spatial relationships of external representational items are retained in internal representations. Further, Shu-Nu and Yao (2014) pointed out that model can also be considered as another construct of visualization which is closely related with representations. A model in science education can be defined as a simplified representation of a phenomenon, which is used to simulate its functionality. However, visualization is not so simple because it includes cognitive and brain processes as well, not a mere pictorial representation (Reiner, 2008).

Beside the complex nature of the field of visualization, use of external representations to elaborate the visualization aspect of science subjects can be recognized as a practical way to help students to better visualize scientific concepts. This study focuses on how the above mentioned visual mode (limited to diagrams, video clips, animations and simulations) can be used to elaborate the visualization aspect of two secondary school physics lessons, kinematics and Newton's laws of motion, presently taught under the physics component of grade 10 science syllabus (National Institute of Education, 2015) implemented from the year 2015 in the secondary school level in Sri Lanka (students of age 15 years). The reason for selecting kinematics and Newton's laws of motion in the grade 10 syllabus is that they are the introductory lessons in many other physics courses as well and on these lessons, students' self-confidence can be easily built. These two lessons incidentally happened to be rich in visualization content too. Therefore, it is worthwhile to select these lessons for experimenting on the effect of this new teaching intervention emphasizing visualization aspect at classroom teaching.

When considering the secondary school students' (grade 11) physics performance it is revealed that the performance need be improved as per the examiner's reports for the subject science at General Certificate of Education-Ordinary Level Examination (GCE-OL), issued by Department of Examinations, Sri Lanka for the period of 2009-2015, where marks for physics in respect of structured essay and essay type questions (question number 4, and question number 9 or 10 in paper II) show that nearly 50% of the students scored marks in range of 0-25% (the GCE-OL curriculum is a two year course and, the grades 10 and 11 are its first year and second year respectively where a particular lesson is covered once during this two year period). Though this study is limited to kinematics and Newton's laws of motion at GCE-OL, the same approach can be extended to other physics lessons such as waves, optics, current electricity, electromagnetism, electronics, hydrostatics, etc., making it a new method worthy of trying out for the purpose of improving the students' low physics performance at GCE-OL.

2. Literature Review

Some of the areas which provide a background (supporting literature) for studying the impact of visualization on science subjects can be motioned as, (a) theories on visual-learning, (b) studies done in the field of spatial ability, (c) studies done in the fields of representations, representational competence, models and modeling in science education. Almost all of these areas are interrelated and there are overlappings.

Piaget and Inhedler (1956) argued that the child's cognitive development progresses through in relation with his/her spatial cognition. Piaget and Inhelder (1967) said that the child's early spatial conceptions are topological in nature. They mentioned that at about 12 or 13 years of age the child is able to visualize the concepts such as area, volume, and distance in combination with those of translation, rotation, and reflection, which are essential in learning physics. Piaget also emphasized the role of building schemas in his classic theory of Developmental Psychology. Students can solve science problems by activating an appropriate schema such as a scientific model/equation in physics that will help them to find the correct answer. Wiley (1990) presented a hierarchy of visual learning, which is partly based on Piaget's work consisting of three stages of visual learning as visual cognition (or perceiving a visual image), visual production (or creating a visual object) and visual resolve (or comprehending the purpose of a visual object). The Dual Coding Theory (DCT) (Paivio, 1986; Sadoski & Paivio, 2001) treats visualization as a way for understanding how linguistic information (words and sentences) and visual information (images) are encoded by two independent mental systems, a verbal one and a nonverbal one. It can be considered that this theory provides a certain scientific insight into how the visualization relates with memory and how visualization may be used to improve learning and understanding. The Visual Imagery Hypothesis (VIH) (Johnson-Laird, 1998; Pylyshyn, 2003) says that graphical representations allow one to process information more efficiently than do verbal ones, ultimately reducing the demand on working memory. The DCT and the VIH are the most frequently used theoretical foundations for many recent studies on visualization in science education especially when using computer based visualization tools (Vavra et al., 2011).

It is proven that there is a positive correlation between the students' performance in spatial ability tests and their performance in Science, Technology, Engineering and

Mathematics (STEM) subjects (e.g. Shea, Lubinski, & Benbow, 2001; Uttal & Cohen, 2012; Wai, Lubinski, & Benbow, 2009). Spatial ability can be generally termed as one's ability to visualize, transform, and manipulate non-verbal information, such as symbols, figures, and 2-D and 3-D objects based on visual stimuli (Carroll, 1993; Linn & Petersen, 1985; McGee, 1979) and it consists of various sub levels which are called spatial ability factors. Also researchers have shown that the spatial ability can be improved by proper instruction (e.g. Hand, Uttal, Marulis, & Newcombe, 2008; Sorby, 2009; Sorby & Baartmans, 2000). With the general understanding of the spatial ability as a successful predictor in STEM education, physics educationists also conducted spatial research, basically with the aim of identifying the spatial ability factors (e.g. mental rotation, metal transformation, spatial orientation) correlated with various physics domains (e.g. Pallrand & Seeber, 1984; Kozhevnikov, Motes & Hegarty, 2007; Lyna & Fulmer, 2014). The researchers' attention on this kind of spatial research can be thought of as one of the major factor which influenced the researchers' to think about the importance of formation of mental images in science subjects. As an implication of spatial ability research, it can be mentioned that if a student is good at the skills such as mental rotation, mental cutting, viewing cross sections, etc., it is reasonable to generally guess that the student can understand the diagrams in physics easily and can build the necessary mental images easily.

Physics education involves use of various representations such as diagrams, graphs, symbols, computer aided visualization tools such as video clips, animations and simulations where "representations play a vital role in the explanations of natural phenomena that physics provides" (Yeo & Gilbert, 2017. p. 255). The skills of dealing with these representations are called representational competence (Kozma & Russell, 2005). Representational Competence (Kohl & Finkelstein, 2005; Kohl & Finkelstein, 2006) is needed to work exclusively with representations, in physics, chemistry or biology. The expert level of this skill is called meta-representational competence (MRC). In this context, "*visualizations defined as the process of making meaning out of representations*" (Hill, Sharma, O'Byrne, & Airey, 2014. p.25). Multi-representational instruction and simulations can be considered as means of improving representational competence in science education (Steiff, 2011; Opfermann, Schmeck, & Fischer, 2017). Wong and Chu (2017) mentioned that though physics teachers use multiple representations in classroom teaching they may not sufficiently pay their attention on step by step development of concepts through the use of these representations (with relevance to teaching electric current). Nieminen, Savinainen, and Viiri (2017) pointed out the importance of multiple representations in teaching forces for upper secondary students.

These external representation modes are used by learners to construct their internal (private) models (Rapp & Kurby, 2008; Gilbert, 2005) which are the internal representations that matters in their individual understanding. The teacher can represent the external models by way of a diagram, a physical practical set up, a computer simulation/animation, etc. (Evagorou, Erduran, & Mäntylä, 2015; Mnguni, 2014), built models such as lattice structure of crystal, regular tetrahedral model of carbon, planetary model of atom, etc. and they all come under public models where everybody has a common agreement on them. Then the student builds their own internal (mental) private models (Gilbert, 2005) where his/her background can also infer to make individual differences. Therefore, to bring uniformity into this internal representation among students at least to a certain extent, teacher is advised to use more than one mode of external representation such as verbal communication, similies common to students' environment, etc. The external models used in science education should be public models which the scientific community can agree upon. Also the model based approach to physics can be considered as showing the need of imagination in physics. Buffler, Lubben, Ibrahim, and Pillay (2008) pointed out that the physical models are useful in building conceptual models (mental images). To teach the students physical models and conceptual models the teacher can use the modes of representations appropriately. When dealing with the above mentioned models in science education, the student should have the capability of visualizing the models in three representation levels: the macroscopic, the microscopic (sub-microscopic), and the symbolic (Johnstone, 1993).

When it comes to identifying the visualization related areas to be elaborated in classroom teaching and learning of physics, in general, various visualization aspects such as (a) building a mental image of an object physically seen, drawn, or heard about, (b) comparing physical quantities related with moving objects, (c) spatial imaginations of objects, (d) visualizing spatial relationships and orientations of objects, (e) visualizing algebraic equations, (f) mentally inverting, cross-sectioning or rotating an object, (g) imaginations resulted from some hypothetical scientific models, etc. can be enumerated. Therefore, selecting the most appropriate visualization aspect for elaborating specific subject content at the classroom teaching and assessing its impact on the students' physics performance is, to a large extent, content specific in nature. Because of this broad variety in visualization even in a particular lesson topic, finding a common framework for assessing students' attainment in visualization in physics is difficult and therefore, for a mixed of external representation is preferred.

3. Material and Methods

3.1 Experimental design

This study is a field experiment where an experiment is done in the existing school system. The experiment design used in this study is a 'pre-test and post-test experimental and control group design', which is coming under the 'true experimental designs' and also known as 'ex post facto experimental designs' that include both the experimental and control groups and recording information both before and after the experimental group is exposed to the treatment (Sekaran & Bougie, 2013).Table 1 shows the experimental design.

Table 1: Experimental design of the study

Group	Pre-test	Treatment	Post-test
Experimental	The Visualization Related Physics Test	Use of CAL materials to highlight the visualization aspect, embedded with usual classroom teaching	The Visualization Related Physics Test
Control	The Visualization Related Physics Test		The Visualization Related Physics Test

As shown in Table 1, the two groups - one experimental and the other control - are both exposed to the pre-test and post-test in this design. And the former group is exposed to the treatment and the latter is not. The differences in the post-test and pre-test scores of the two groups give the net effects of the treatment. Both groups have been randomized. As shown in Table 1, the experiment group is taught physics lessons by using CAL materials to highlight the visualization aspect by reinforcing the usual classroom teaching while the control group is also taught the same physics lesson of the same duration as for the experimental group without giving any deliberate attention on highlighting the visualization aspect with/without using CAL materials.

3.2 External and Internal Validity of the Experiment

The validity of a field experiment of this type is an important attribute which is also linked with the experimental design. The validity of an experiment is two-fold: the external validity and internal validity. The external validity of an experiment refers to the extent, to which its results can be generalized to other settings, individuals or events, and the internal validity refers to the degree of confidence in the causal effects (that is, the use of a particular treatment for the experimental group would alone result in increase in the other variable being measured) (Sekaran & Bougie, 2013). Usually the field experiments have more external validity (the results are more generalizable to other similar settings), but less internal validity (being unable to be sure of the causal relationships).

It can be generally said that, this experiment has the external validity as the sample of the students were selected from averagely performed three schools, and all the government schools follow a common curriculum, all the teachers have the minimum qualifications sufficient to teach at government schools, and all the teachers were given the same in-service teacher training by the government. As the measures taken to ensure the internal validity of the experiment, random assignment of students to the experimental and control groups, conducting the experiment as an extended learning session to the usual classroom schedule with participation of school science teachers, giving no incentives for the students of either group for their participation, conducting the experiment during a time period (March-June) where the students are not getting prepared in full strength for the end of year examination (conducted in December) by mechanically practicing to answer examination type questions by participating in various seminars, revision sessions, etc. can be mentioned.

3.3 The Student Sample for Testing the Effect of the Visualization Tools

A sample of 184 students studying at grade 10 during the time of experiment (from end of March to end of June 2017) from three nearly equally and averagely performed government schools (Table 2) where the students' cultural and family backgrounds are also quite similar and located in Colombo district were selected for the study. During the time of the experiment, the participating students have completed kinematics and Newton's laws of motion at their usual classes as per the prescribed learning sequence given in the syllabus (kinematics and Newton's laws of motion have to be finished by March). Additional teaching for the participating students had to be done after the school hours. Therefore, the students who are willing to stay after the school hours and two science teachers (for the experimental group and the control group) from each of the three schools who are willing to conduct additional teaching had to be selected. This was also considered in selecting these three schools. All the students and teachers participated in the experiment voluntarily (the medium of instruction was Sinhala in all three schools). The distribution of the students among schools and the groups are given in Table 2 below.

Table 2: Composition of the sample

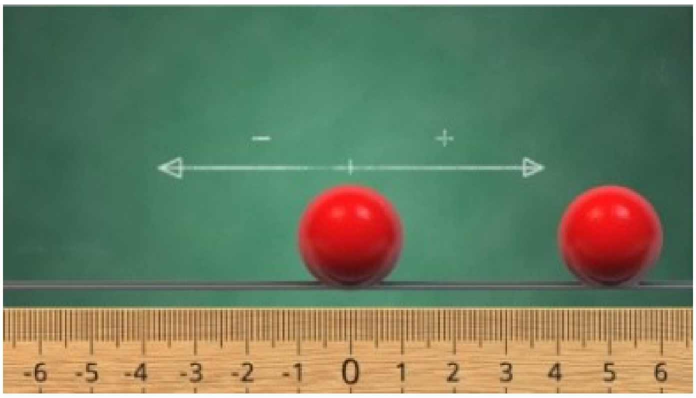
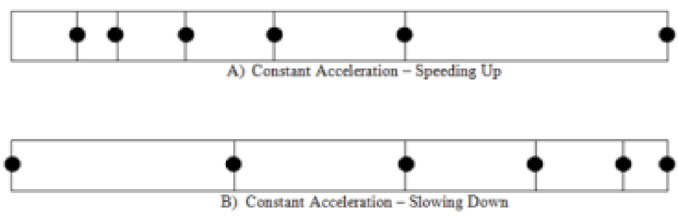
Name of school	**Participated number of students**	
	Experimental group	**Control group**
WP/Pili/Buddhist Girls' College (BGC), Mount Lavinia	29	29
WP/Pili/ Colombo South Science College (SC), Mount Lavinia (Boys' school)	31	30
WP/Pili/ Dehiwala S.de S. Jayasinghe Central College (DCC), Dehiwala (Boys' and girls' mixed school) (17 girls and 38 boys participated)	32	33
Total	92	92

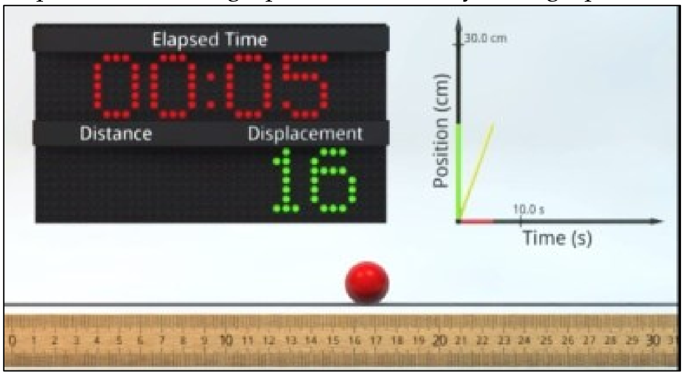
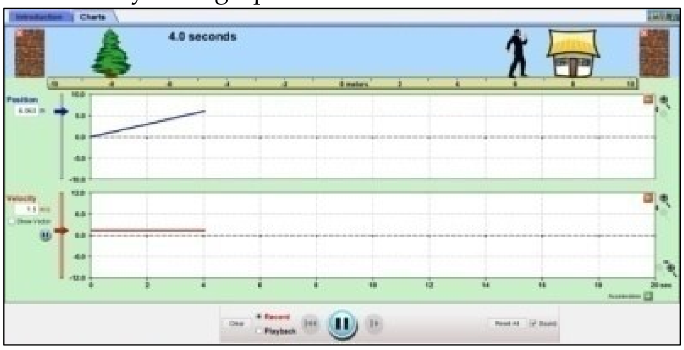
From each school the students were grouped in to experimental group and control group. The students were assigned to the groups randomly. The whole experimental group and control group comprise of the students from all the three schools. In this study, no school-wise differences or gender-wise differences were of interest. However, measures were taken to represent both girls and boys quite equally in the sample by selecting the students from a girls' school, a boys' school and, a girls' and boys' mixed school.

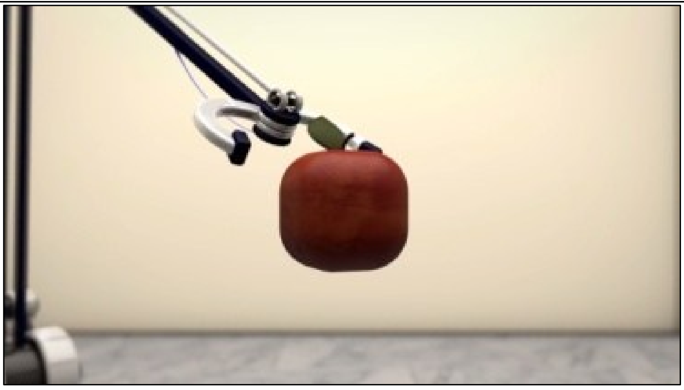
3.4 Notable Visualization Related Areas

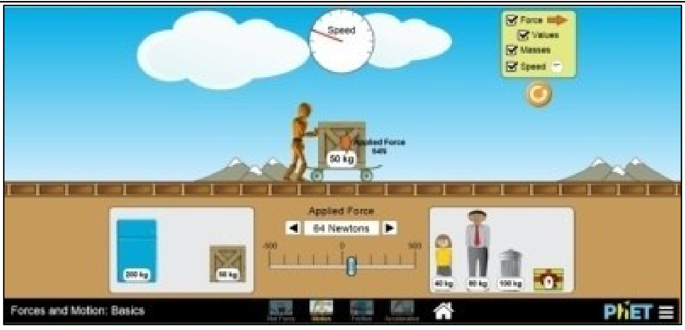
Some of the notable visualization related areas of kinematics and Newton's laws of motion were identified after going through the grade 10 science syllabus and the teacher's guide (National Institute of Education, 2015), and the school textbook (Educational Publication Department, 2015). Suitable diagrams, video clips, animations and simulations which match with the limitations of the learning outcomes of the grade 10 science syllabus were selected mainly through search on the internet, most of these materials being available free of charge. Table 3 gives a brief description on these areas, how the selected materials can be used to emphasize the visualization aspect involved and the problem areas in visualization aimed to correct by using the material. Also a sample screen from the learning material is shown in the table.

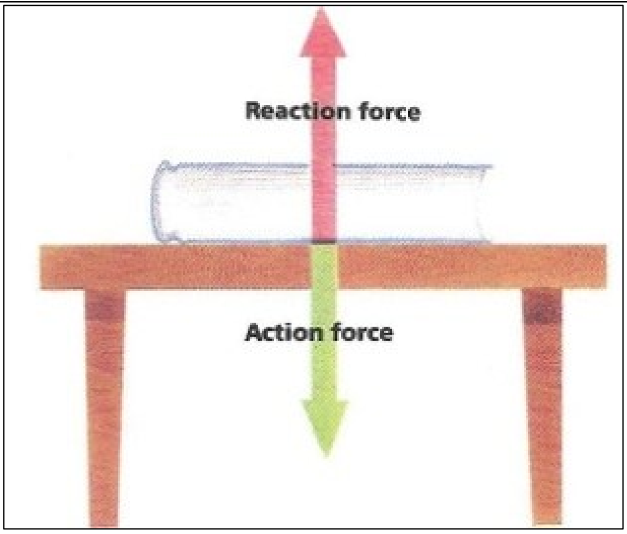
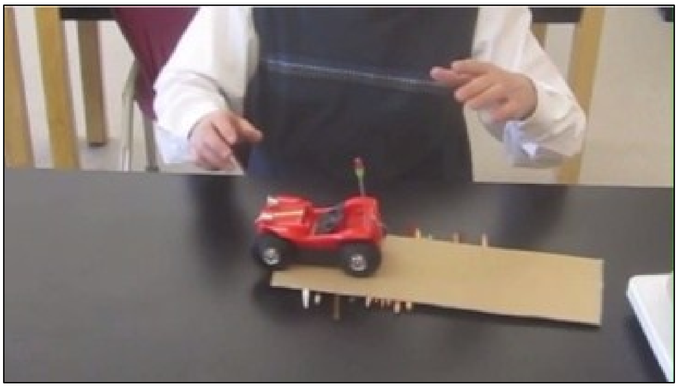
Table 3: Notable visualization related areas and materials used in visualization

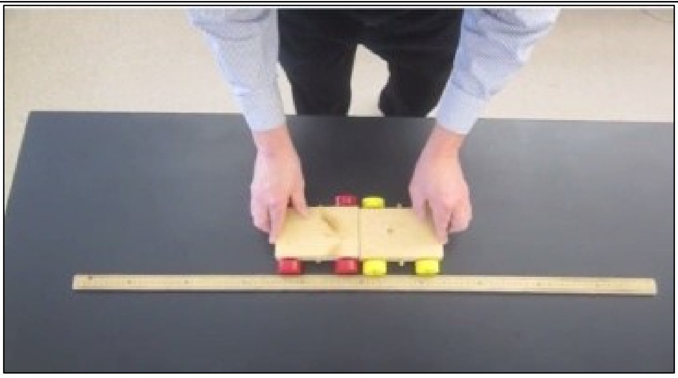
Notable visualization related area	Brief description of how the material helped in visualizing the concept underlined with a sample screen	Problem area in visualization aimed to correct with explanations using the material
Kinematics:		
(i) Differentiating the distance and displacement, and its impact on average speed and average velocity by visualizing the rectilinear motion of an object (treating plus and minus signs of the displacement and velocity).	Screen display of a ball moving on a straight line path which shows how the values of distance and displacement changes on real-time  *Source: An animation developed by www.tiros.ca (https://www.youtube.com/watch?v=UefWw5k4G0U)*	Not concerning the starting point where it starts to measure distance or displacement. Inability to take into account the change of sign in displacement when calculating the total displacement
(ii)Interpreting the acceleration in terms of change in the distance or displacement.	Diagrams indicating the position of the moving object at the end of each second by a dot. Comparison of motion of two objects to the same direction can be explained using these diagrams: illustrations of (a) slow and fast constant speed, (b) speeding up and speeding down, (c) constant speed and acceleration.  *Source:* *Diagrams taken from* *http://study.com/academy/lesson/constant-motion-in-physics-definition-lesson-quiz.html,* *http://study.com/academy/lesson/constant-motion-in-physics-definition-lesson-quiz.html,* *http://www.physicsclassroom.com/class/1DKin/Lesson-2/Ticker-*	Inability to match the pattern of changing the distance (displacement) of a moving object with how its speed (velocity) changes.

Notable visualization related area	Brief description of how the material helped in visualizing the concept underlined with a sample screen	Problem area in visualization aimed to correct with explanations using the material
	Tape-Diagrams	
(iii)Interpretation of displacement-time and velocity-time graphs.	Screen display of the displacement-time graph of a moving object at real-time. Also it shows the conversion of a displacement-time graph in to a velocity-time graph.  *Source:* *An animation developed by www.tiros.ca (http://www.physicsclassroom.com/class/1DKin/Lesson-6/Kinematic-Equations-and-Graphs)*	Inability to transfer how the displacement changes over time to the two axes; displacement and time of a 2-D graph.
	Screen display of the real-time drawing of displacement-time and velocity-time graphs on the same screen.  *Source:* *An interactive PhET simulation, 'Moving man' (https://phet.colorado.edu/en/simulation/legacy/moving-man)*	Inability to relate rectilinear motion, with displacement-time graph and velocity-time graph. Inability to convert a displacement-time graph into a velocity-time graph and vice versa.
Newton's laws of motion:		
(i)Visualizing the effect of an object kept on zero gravity, zero air pressure (Newton's first	Screen display of an idealized room under zero gravity, zero air pressure, and zero surface friction, where an apple is placed in the space of the room. The students can visualize what happens to the apple when a force is applied to it, and then releasing the force.	Inability to perceive the effect of constant velocity when there is no net external force

Notable visualization related area	Brief description of how the material helped in visualizing the concept underlined with a sample screen	Problem area in visualization aimed to correct with explanations using the material
law).	 *Source:* *An animation developed by www.tiros.ca* *(https://www.youtube.com/watch?v=NYVMImL0BPQ)*	applied on an object
(ii)Visually predicting the effect of a constant force applied to an object continuously for a certain time in term of its speed.	Screen display of a trolley on a flat surface (table) which was attached by a light inextensible string to a weight going through a pulley fixed at an edge of the table so that when the weight is released from the rest the trolley starts to move.  *Source:* *A video clip* *(https://www.youtube.com/watch?v=B7_oU3HrnBI)*	Inability to predict the effect of applying the same constant force for an object for some time and relate it with the equation, $F = ma$.
	Screen display of how the speed of the object changes by a speedometer when a constant force is applied to it continuously.	Wrong conception that when a constant force is applied to an object for some time the object will move with a constant velocity

Notable visualization related area	Brief description of how the material helped in visualizing the concept underlined with a sample screen	Problem area in visualization aimed to correct with explanations using the material
	 *Source:* *An interactive PhET simulation, Motion' sub module under 'Force and Motion'* *(https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_en.html)*	during that time. (may be due to day-to-day experiences such as when a car or motor-bike is accelerated by pressing the same amount of the accelerator paddle it moves with a constant velocity in a straight horizontal stretch of a road)
(iii)Visualizing the effect of varying the variable *F* keeping the variable *m* constant in the equation, *F* = *ma* in terms of the variable *a*, and visualizing the effect of varying the variable *m* keeping the variable *F* constant in the equation, *F* = *ma* in terms of the variable *a*	Screen display of the above set up of the trolley and the weight by comparing the speed of the trolley by increasing the weight (keeping the mass of the trolley constant) at one instance and by increasing the mass of the trolley (by keeping the weight hung constant) in the other instance.  *Source:* *A video clip (https://www.youtube.com/watch?v=B7_oU3HrnBI)*	Inability to practically relate how the acceleration changes with mass of the object and the external force applied to an object in view of deriving the relation *F* = *ma.*
(iv)Imagination of action force and reaction force under Newton's third law of motion.	A diagram clearly indicating the action force and reaction force.	In ability to build the mental image that the two forces coming under the action and reaction pair of force act on two distinct objects without mixing it

Notable visualization related area	Brief description of how the material helped in visualizing the concept underlined with a sample screen	Problem area in visualization aimed to correct with explanations using the material
	 *Source:* *A diagram taken from* *https://study.com/academy/lesson/action-and-reaction-forces-law-examples-quiz.html*	with the forces under which the object is under the force equilibrium.
	Screen display of a toy car moving on top of a cardboard placed on a set of pencils kept on the surface of a table, perpendicular to the direction of motion of the car.  *Source:* *A video clip* *(https://www.youtube.com/watch?v=N_V_848AxZM)*	Inability to practically visualize the effect of the action force and the reaction force acting on two distinct objects.
	Screen display of the distances travelled by two trolleys on a horizontal surface, pressed together with the spring of one trolley to the other after they have been released.	Inability to practically see that the magnitude of the action force and the reaction force

Notable visualization related area	Brief description of how the material helped in visualizing the concept underlined with a sample screen	Problem area in visualization aimed to correct with explanations using the material
	 *Source:* *A video clip* *(https://www.youtube.com/watch?v=IRtBnhrEe94)*	are equal, they act on two distinct objects, in opposite directions (here it must be stressed that the action force and the reaction force disappear once the two trolleys have been released and only the effect of the two forces are depicted by the equal distances travelled by the two trolleys to opposite directions)

The visualization related areas selected in Table 3 cannot be fully understood through observations alone since forming some mental images is imperative (in the experimental teaching, the relevant areas in the above mentioned materials which are in English medium were explained to the students in Sinhala medium).

3.5 Pilot Testing of the Teaching Approach

However, before starting the experiment in March 2017, this new method was pilot tested with a group of grade 10 students in May and June of 2016 nearly one year ago. In order to identify the visualization related areas and develop the questions to assess students' competence level in visualizing the concepts, this pilot testing was helpful. Based on the discussions held with the students, several areas of misconceptions in respect of visualization in the two lessons could be identified which paved the way to develop the visualization related physics questions (which will be discussed below). For this pilot testing, 61 students in two classes of the two schools, SC and DCC participated. These students were at their grade 10 in 2016 and they did not participate in the main experiment.

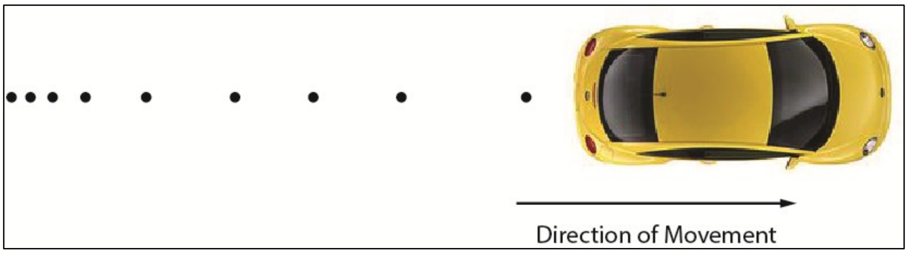
3.6 Development of Suitable Items (Questions) to Assess Students' Attainment in Visualization Aspect of the Two Lessons

To assess the students' attainment level of visualization aspect on kinematics and Newton's laws of motion, 14 multiple choice-type questions (MCQ's) (containing four answer choices) were specifically developed. This physics question paper, which is lesson specific assessment tool developed in this study is referred to as Visualization Related Physics Test (VRPT). It is to be answered within 30 minutes. To conveniently administer the question paper to the sample students within a classroom period of 40 minutes, the number of questions was limited 14. To answer these questions set on the said two topics successfully, certain amount of visualization is usually needed and that aspect was given special emphasis in the teaching sessions given to the experimental group only. Therefore, special care was taken not to connect the learning materials mentioned in Table 1 directly to these questions. This makes sure the control group students not being familiar with the new learning materials used with the experimental group do not experience any difficulty in understanding the questions. The fact that the questions match with the depth of the grade 10 syllabus and they contain a considerable visualization component were assured by getting the comments from the participating science teachers and a group of subject experts (content validity of the questions). Four of the sample questions (English translations of the original question prepared in Sinhala) are discussed below with a description of visualization involved.

3.7 Sample Questions of Visualization Related Physics Test (VRPT)

Question 1

Due to an oil leakage of the engine of a motor vehicle an oil drop drips from it at each second. When the vehicle continuously moves forward on a straight horizontal road, a strip of places where the oil drops dripped one after the other are marked on the road as shown in the diagram below.



Which of the following statement is correct regarding the above motion of the vehicle?

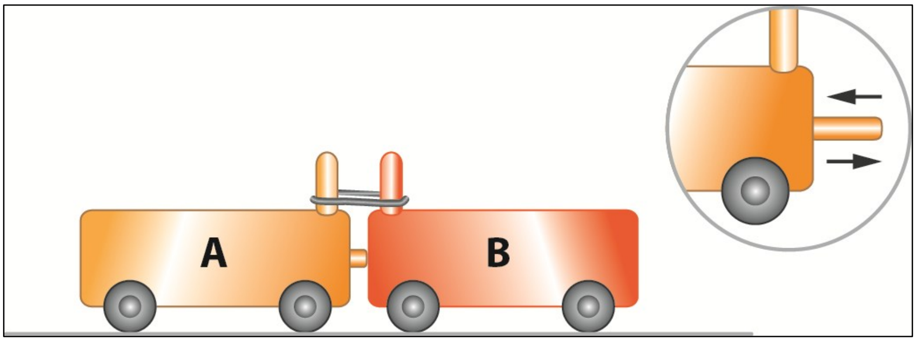
a) The vehicle has moved with constant velocity.
b) The vehicle has moved with acceleration.
c) The vehicle has moved deceleration
d) The information is not sufficient to guess the motion as above.

Visualization involved:

In this question, the student needs to visualize how the distance changes in a unit time interval in relation with the nature of motion of the object. That is whether it is at rest, it moves with constant velocity or it moves with acceleration.

Question 8

The two identical trolleys, A and B are on a uniform rough horizontal surface. They are joined by a string as shown above so that their inbuilt springs are pressed one another.



If the mass of the trolley B is doubled, what is true out of the following statements regarding the motion of the two trolleys until they come to rest if the string is cut?

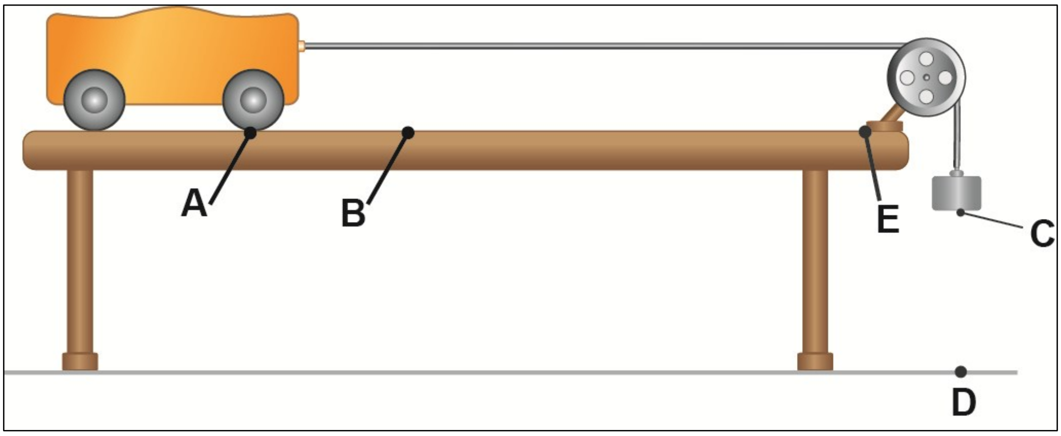
a) B travels four times the distance travelled by A.
b) B travels twice the distance travelled by A.
c) B travels half the distance travelled by A.
d) Both A and B travel the same distance.

Visualization involved:

This question requires the student to visualize the motion of the two trolleys once the string is cut. It involves prediction of the distance travels by each trolley considering the weight of the trolley. If the student had shown this kind of activity in classroom teaching by the science teacher then the student could answer this question easily. If this question is interpreted by the Newton's second law of motion, the force applied to a trolley should be taken as the frictional force applied on the trolley in the direction opposite to its direction of motion. Frictional force, F is proportional to the normal reaction,R and R is higher when the mass is higher. Therefore, a greater frictional force will act on the trolley B. Then the trolley B will come to rest earlier than the trolley A. One mistake in visualizing the situation can be considering the action and reaction pair of forces acting on the two trolleys at the very movement of cutting the string exists on the two trolleys until they come to rest and trying to relate the motion of two trolleys coming to rest with this wrong idea. Actually these two action and reaction forces act only at the very moment the string is cut and no way it can be further used in explaining how the two trolleys come to rest. But if the two trolleys are identical, then the two trolleys will travel the same distance and then come to rest. Travelling the same distances apart in the case of two trolleys are identical may be explained to the students as showing an indication that the action and reaction forces instantaneously acted on the two trolleys when the string is cut are equal in magnitude, applied on the two objects (the two trolleys) in the opposite directions.

Question 9

The diagram shows an experimental set up containing a trolley kept on horizontal smooth table. The trolley is attached a light string which goes through a smooth pulley fixed to the edge of the table and a weight is hung from the other end of the string. When the weight is released from the rest at C, it hits the ground at D.
AB = CD



Which of the following statements is true regarding AB and BE motions of the trolley?

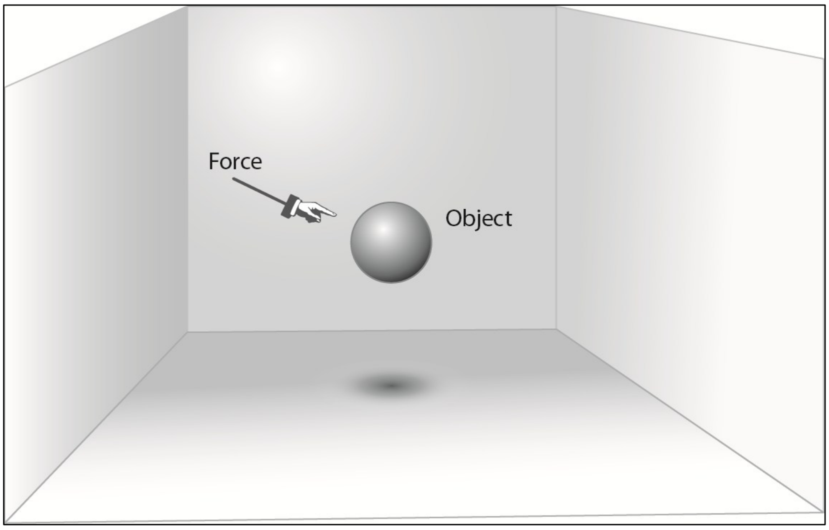
	AB	BE
a)	Acceleration	Uniform velocity
b)	Acceleration	Acceleration of magnitude which is less than that in AB
c)	Acceleration	Deceleration
d)	Uniform velocity	Uniform velocity of magnitude which is less than that in AB

Visualization involved:
To answer this question the student should be able to visualize the second law of motion ($F = ma$) in respect of the movement of trolley between A and B. And its motion from B to E should be visualized according to the first law of motion which says, 'until an unbalanced force is applied on it (in the absence of F), bodies at rest remain stationary and bodies in motion continue to move at uniform velocities'. To explain the AB motion of the trolley, the student must know what happen if a constant force is applied to an object for a certain time. According to the Newton's second law of motion, $F = ma$, then there should be an acceleration. Then in interpreting the BE motion of the trolley, the student should apply the Newton's first law of motion as there is no external force applied on the trolley by the weight (already hit the earth) or no frictional force exists between the trolley and the table surface (table is smooth).

Question 12

The diagram shows a 3-D view of room under idealized conditions: zero gravity, zero air pressure (no air resistance) and, all the inside surfaces of the walls are frictionless.

Assume that an object is placed inside the room in the space (without touching any surface of the room) as shown in the diagram. A push is given to the object into the shown direction and then the push is released.



Three statements are given regarding the situation.

1. Before applying the force it will stay at the same initial position,
2. It will travel with the velocity it attained when the push is released until it hits on a surface of the room.
3. After hitting on a surface of the room also its speed will remain unchanged

Which of the above statement(s) is/ are correct?

a) Only i
b) Only ii
c) Only I and ii
d) All the three

Visualization involved:
The above question tests whether the student can have a clear imagination of the conditions in the Newton's first law of motion. The student needs to imagine this idealized situation first. And the student should imagine what the effects of zero gravity, zero air pressure and zero surface friction are. Then by relating the image the student built with the conditions of the Newton's first law of motion, the student should be able to visualize that the object will stay in the same initial position until an external force is applied and then once that force is applied and released the object will continue with moving to the direction of the force with the velocity it attained when the force is released. Also in this question the student must differentiate between the speed and velocity. Once the object hits on a surface of the room, as the surfaces are frictionless, the object will collide with the same speed but the direction of its motion may change depending on the angle it hits the surface (speed does not change but the velocity changes as the direction of motion changes). Therefore, this question can be

measuring a certain portion of the visualization aspect involved in Newton's first law of motion.

3.7 Pilot Testing of the Physics Questions

For testing the reliability of this question paper (assessment tool), it was given to 58 grade 10 students in the three schools who did not participate in the experiment either as control group or experimental group. A Cronbach's alpha value of 0.701 was obtained (above 0.7). Therefore, the test can be considered as a reliable instrument (Santrock, 2009).

3.8 Questionnaire to Get Students' Feedback for the New Approach

A questionnaire was also designed to assess the students' adaptability to this new approach of teaching and it consists of 10 items spread over four major areas (Table 4).

Table 4: Distribution of test items in students' feedback form

Area	**Number of items**
Use of Technology (adaptability)	2
Quality of the lessons	3
Attitude towards the new approach	3
Overall view on participating in the study	2
	10

3.9 Conducting the Main Experiment

At the end of March 2017, the physics test consisting of visualization related questions, which is referred to as Visualization Related Physics Test (VRPT) were administered to all the participating students as a pre-test. Thereafter, the students were randomly assigned to the two groups namely, the experimental group and the control group. Then additional teaching was done for both the groups. However, the new approach was followed for the experimental group only while the usual teaching was done for the control group (8 periods of additional teaching). These additional classes were conducted by school science teachers (one teacher for the experimental group and another for the control group: they had been briefed on the suggested teaching approach and the experimental plan in detail). These classes were conducted during May and June of 2017 (as one period per week conducted after school). At the end of teaching both the groups were administered VRPT as a post-test. Here, the same question paper was given as a surprise.

During the teaching sessions, classroom observations were noted. Also several unstructured discussions were held with the students in the experimental group to ascertain the effectiveness of the new teaching approach. At the end of the experimental teaching the students' views on the new approach were surveyed using a questionnaire (Table 4) given to the students in the experimental group.

3.10 Methods of Statistical Analysis

For testing the reliability of the VRPT, Cronbach's alpha value was calculated. Descriptive statistics such as mean, standard deviation and skewness have been calculated where necessary. Group comparison tests were used to compare the treatment effects.

4. Results and Discussion

Cronbach's alpha value for the pre-test administration of VRPT was calculated and it came to 0.711 further confirming the reliability of this assessment tool.

The total marks for VRPT obtained by a student were calculated by adding the total number of correct answers made by the students out of the 14 questions. Table 5 shows the mean total score for a question in VRPT with the standard deviation (the score calculated as a percentage is shown within the brackets).

Table 5: The mean total scores for VRPT

Group	Pre-test		Post-test		Percentage increase in post-test compared to pre-test
	Total marks	Standard deviation	Total marks	Standard deviation	
Experimental	4.620 (33.003%)	1.778 (12.703%)	6.567 (49.909%)	2.072 (14.804%)	13.906%
Control	5.012 (35.801%)	2.061 (14.721%)	5.198 (37.131%)	2.106 (15.044%)	1.330%

Table 5 shows a gain of about 14% in the post-test performance in the experimental group compared to the pre-test whereas that in the control group is only around 1%. Further, it shows quite high standard deviations on students' VRPT scores.

How the students' question-wise performance varied between the pre-test and the post-test administration of the VRPT for the experimental group is given below in Table 6. When testing the significance of the difference between the pre-test and the post-test of individual questions (related group comparison), the McNemar test was used as the variables are dichotomous.

Table 6: Students' performance for VRPT in the experimental group

Question number	Percentage of students correctly answered the question		Percentage increase of students correctly answered at the post-test compared to the pre-test	p-value from McNemar Test
	Pre-Test	Post-Test		
01	72%	73%	1%	0.500*
02	76%	76%	0%	-
03	40%	49%	9%	0.000
04	71%	71%	0%	-
05	36%	44%	8%	0.000
06	15%	31%	16%	0.000
07	17%	29%	13%	0.000
08	27%	42%	16%	0.000
09	12%	21%	9%	0.000

Question number	Percentage of students correctly answered the question		Percentage increase of students correctly answered at the post-test compared to the pre-test	p-value from McNemar Test
	Pre-Test	Post-Test		
10	16%	29%	13%	0.000
11	49%	58%	10%	0.000
12	9%	29%	20%	0.000
13	5%	47%	42%	0.000
14	18%	57%	39%	0.000
Overall percentage	33%	47%		

As shown in Table 6, the questions 02 and 04 do not show any differences of performance in the physics test between the pre-test and the post-test. Over 70% of students correctly answered these two items in the pre-test itself. In question 01, the post-test score has improved by only 1% and this difference is not significant as the p-value is more than 0.05 (indicated by an asterisks mark in the first row of Table 6). In each of the other questions, there is a significant difference between the pre-test and the post-test performances as revealed by the p-values which are less than 0.05 as shown in Table 6. Figure 1 shows the same information graphically.

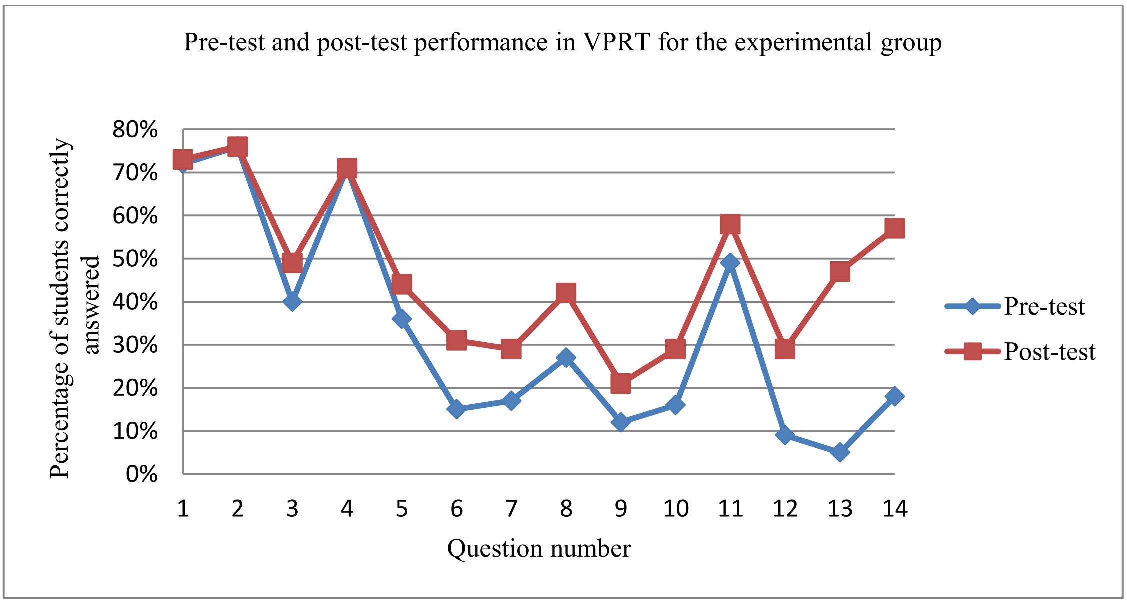


Figure 1: Question-wise performance for VRPT at pre-test and post-test for the experimental group

As shown in Figure 1, for the questions 1, 2, and 3, the students have already achieved the required level in the pre-test also. For the questions 6, 7, 8, 12, 13 and 14, the experimental group show higher improvements indicating that the materials used for the experimental group are more effective. On the average, it is clear from Figure 1 that the materials used for Newton's laws of motion (question numbers, 8-14) are more effective than those used for kinematics (question numbers, 1-7). Similarly, the students' performance at VPRT in the control group is given in Table 7.

According to Table 7, the questions, 1, 2, 3, 4, 7, 9, 11, and 12 do not any change in students' overall responses. Though the question 13 shows a 1% increase in students' performance, it is not significant as the p-value from the McNemar test is above 0.05. The questions 5, 6, 8, 10 and 14 show significant improvements in the post-test compared to the pre-test for the control group as the p-values from the McNemar test are less than 0.05. Figure 2 graphically represents the control group performance for VRPT.

Table 7: Students' performance for VRPT in the control group

Question number	Percentage of students correctly answered the question		Percentage increase of students correctly answered at the post-test compared to the pre-test	p-value from McNemar Test
	Pre-Test	Post-Test		
01	63%	63%	0%	-
02	83%	83%	0%	-
03	54%	54%	0%	-
04	66%	66%	0%	-
05	38%	40%	2%	0.014
06	15%	17%	2%	0.014
07	28%	28%	0%	-
08	27%	31%	4%	0.002
09	26%	26%	0%	-
10	11%	15%	4%	0.002
11	46%	46%	0%	-
12	6%	6%	0%	-
13	2%	4%	1%	0.083*
14	36%	40%	4%	0.002
Overall percentage	36%	37%		

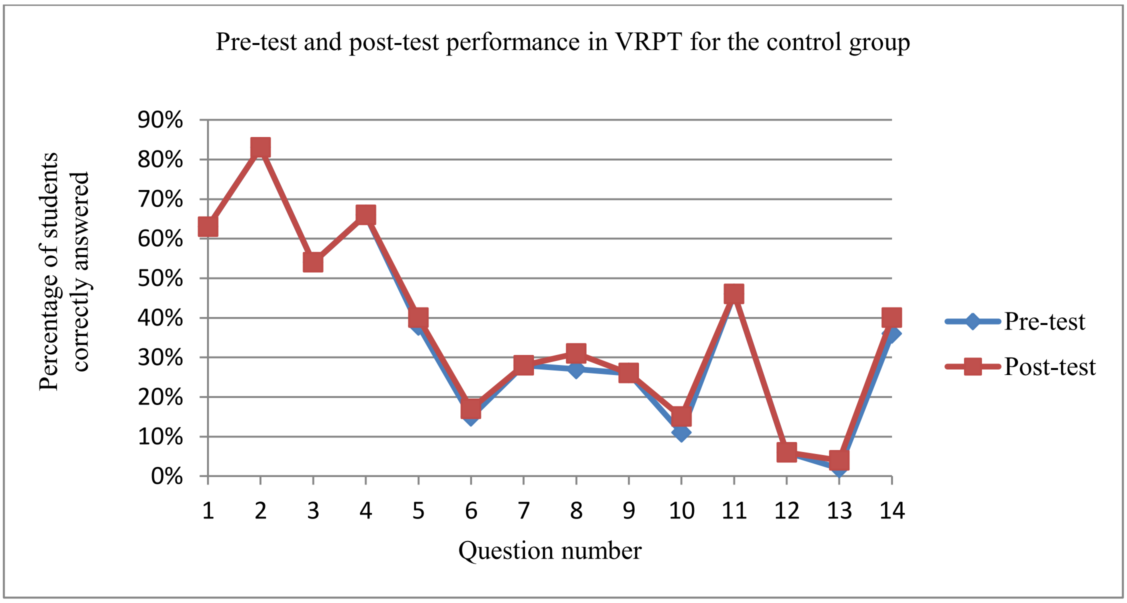


Figure 2: Question-wise performance for VRPT at pre-test and post-test for the control group

Figure 2 shows that the post-performance of control group does not show remarkable improvements. It is evident from the results that the usual teaching does not help students in improving their ability to visualize the necessary concepts.

On the average in the experimental group, around 33% of the students correctly answered a question in the pre-test of VRPT and at the post-test it was around 47%. Similarly, in the control group, these percentages amount to 36% and 37% respectively in the pre-test and the post-test (the same information are provided in Table 5 converted to percentages or by averaging pre-test and post-test columns in Table 6 and Table 7). This overall comparison is graphically represented in Figure 3 below.

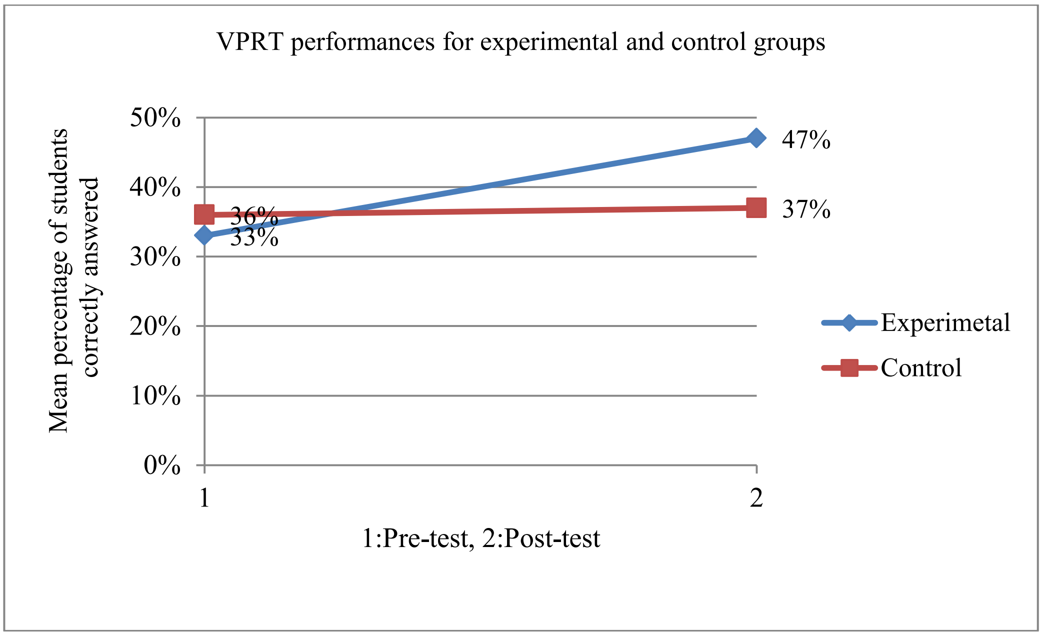


Figure 3: Comparison of mean performances for VRPT at the pre-test and post-test across the experimental and control groups

As shown in Figure 3, though the experimental group pre-test performance are little below than that in the control group, the experimental group have shown remarkable improvements in their attainment in visualizing the necessary content. Also the test items in VRPT are physics questions in line with the syllabus, it can be said that the experimental group students' physics performance has also gone up due to the intervention.

The frequency distribution of students' total marks for kinematics questions in the experimental group is represented in Table 8 and Figure 4. The marks range from 0 to 7.

Table 8: Frequency distribution of students' marks for kinematics questions in the Experimental group

VRPT administration	Number of students who scored the given marks							
	0	1	2	3	4	5	6	7
Pre-Test	0	21	47	78	58	27	14	0
Post-Test	0	15	39	62	47	48	35	0

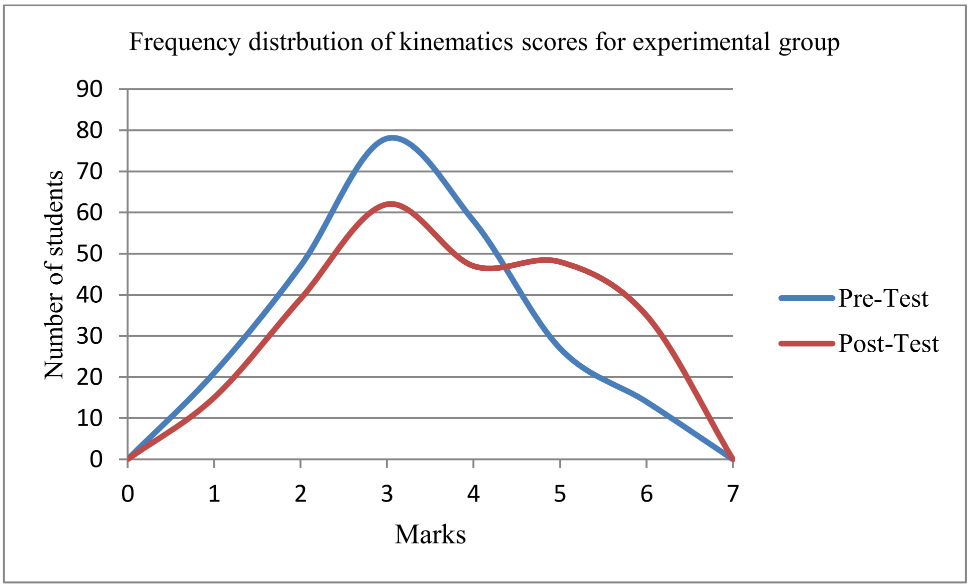


Figure 4: Frequency distribution of total kinematics scores in VRPT for experimental group

Similarly, the frequency distributions of Newton's laws of motion scores are represented in Table 9 and Figure 5.

Table 9: Frequency distribution of students' marks for Newton's laws of motion questions in the Experimental group

VRPT administration	Number of students who scored the given marks							
	0	1	2	3	4	5	6	7
Pre-Test	67	79	58	27	14	0	0	0
Post-Test	10	26	56	71	67	15	0	0

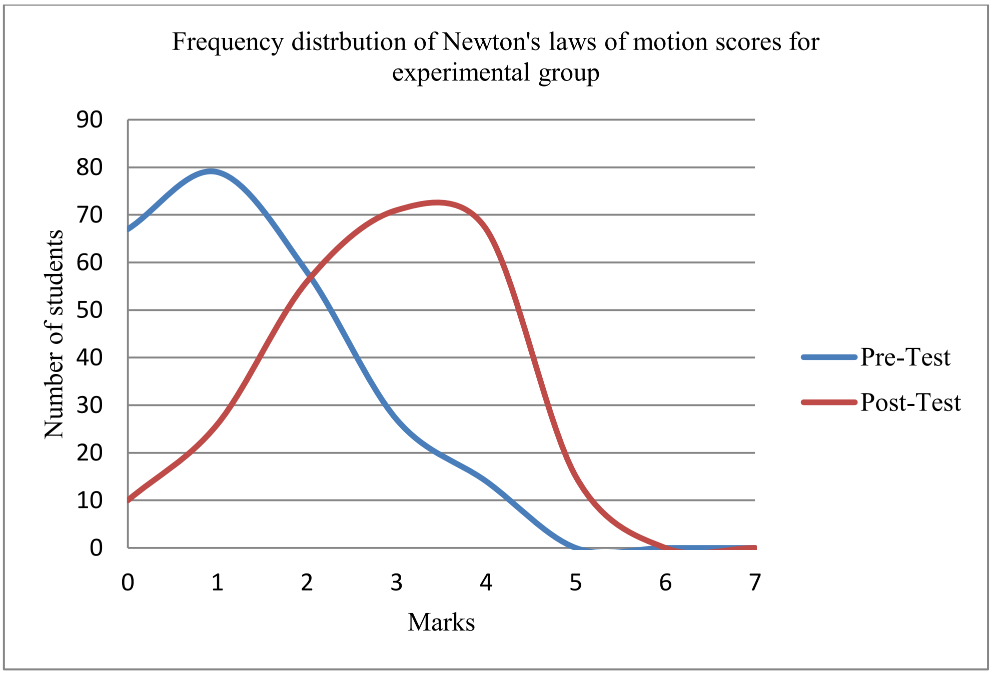


Figure 5: Frequency distribution of total Newton's laws of motion scores in VRPT for experimental group

Figure 4 and Figure 5 show that the frequency distributions moved towards the bell shaped normal curve in the post-test for both the lessons. This is an indication of the successfulness of the intervention for benefiting all the students in the classroom.

The frequency distribution of students' total marks for kinematics questions in the control group is represented in Table 10 and Figure 6. The marks range from 0 to 7.

Table 10: Frequency distribution of students' marks for kinematics questions in the control group

VRPT administration	**Number of students who scored the given marks**							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Pre-Test	0	7	69	69	38	31	32	0
Post-Test	0	7	69	63	44	31	27	5

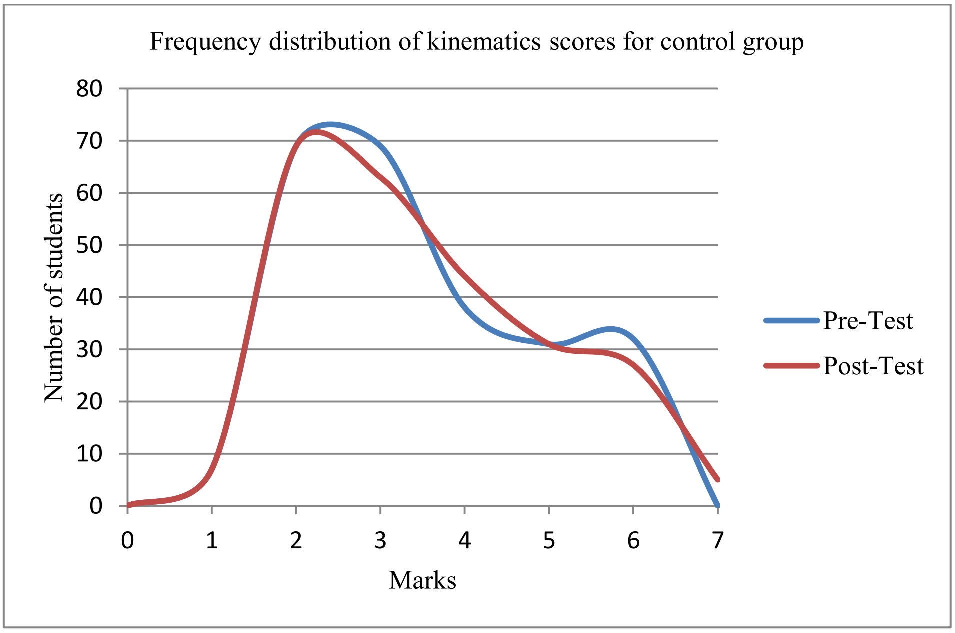


Figure 6: Frequency distribution of total kinematics scores in VRPT for control group

The frequency distributions of Newton's laws of motion scores for the control group are represented in Table 10 and Figure 7.

Table 10: Frequency distribution of students' marks for Newton's laws of motion questions in the control group

VRPT administration	**Number of students who scored the given marks**							
	0	1	2	3	4	5	6	7
Pre-Test	52	67	72	54	1	0	0	0
Post-Test	43	63	76	60	4	0	0	0

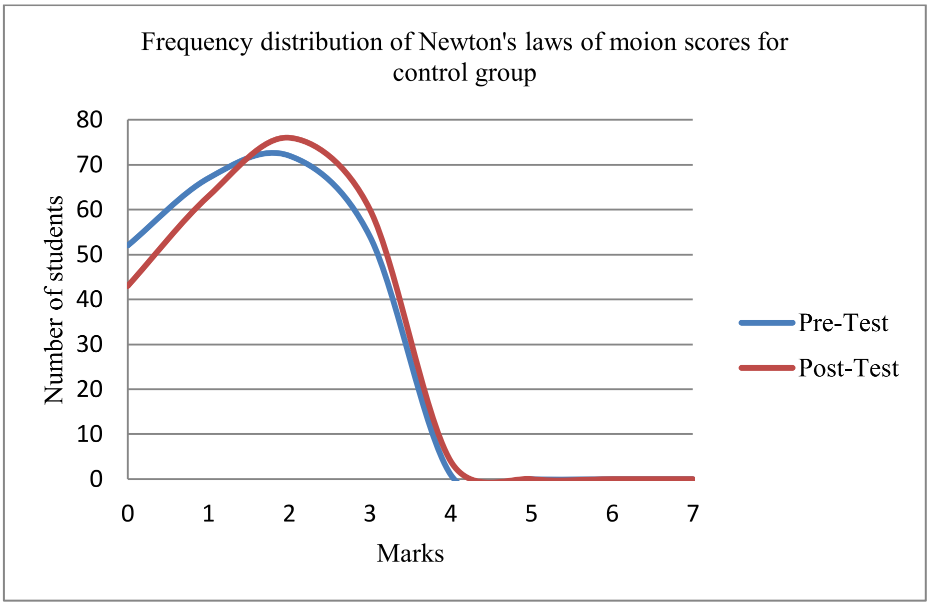


Figure 7: Frequency distribution of total Newton's laws of motion scores in VRPT for control group

Figure 6 and Figure 7 show that the pre-test and post-distributions of VRPT scores for the two lessons in control group are more or less the same. This indicates that there is no salient improvement in the post-test scores compared to the pre-test scores in control group.

4.1 Students' Feedback

The students' feedback form (attached as Appendix-II) was given to all the participating students (92) in the experimental group and 86 were the valid forms correctly answered. There were 10 items (5 point Likert scale) in the form where the students had to select either from 1, 2, 3, 4, or 5 which stands for strongly disagree, disagree, neutral, agree or strongly agree respectively. Students' mean responses are shown in Table 11.

Table 11: Mean scores for the students' feedback form

Area	Item number	Mean	Standard deviation
Use of technology	1	4.393	0.668
	2	4.521	0.737
Quality of the lessons	3	4.154	0.725
	4	4.470	0.675
	5	3.547	0.747
Attitude towards the new approach	6	3.607	0.828
	7	4.436	0.686
	8	4.778	0.417
Overall view on participating in the study	9	4.419	0.721
	10	4.735	0.480
Mean		4.306	

Table 11 shows that the students' response to the intervention is a favourable one (mean response of 4.306). The students' responses for the item 4 (with a mean response of 4.47) imply that the teaching approach helped them to correct certain mistakes in visualizing the concepts in kinematics and Newton's laws of motion. This indicates that the teaching approach is capable of improving the visual-perception in physics. Further the students' said that they were confident that they would be able to answer examination type physics questions with much ease after participating in the lessons (item 5). This provides evidence in support of the successfulness of the teaching approach in improving the general physics performance.

4.2 Classroom Observations and, Discussions/Unstructured Interviews with Students

Classroom observations revealed that the teaching approach used with the experimental group was an interesting learning experience for the students. The interaction with the students (casual discussions with the students) while conducting the lessons confirmed that the teaching approach helped them build the necessary visualizations in physics. After conducting the post-test of VRPT, the researchers got the chance of discussing several of questions (items) of the tool with a small group of participating students from the experimental group selected from two of the schools (12 students from SC and 15 students from DCC). In these discussions also, students freely expressed the views that the items are capable of diagnosing their weak areas of visualizing physics concepts and the lessons using CAL materials have helped them to overcome such weaknesses to a greater extent.

5. Conclusion and Recommendations

This above experimental study is an attempt of emphasizing the visualization aspect of the two secondary school physics lessons, kinematics and Newton's laws of motion basically utilizing the visual-mode of external representations (Gilbert, 2005). Computer aided learning materials such as diagrams (shown through the computer screen), video clips, animations and simulation were used with verbal explanations in this study to highlight the visualization aspect of certain identified areas. These new tools introduced to the lessons supplemented the traditional teaching methods in which the materials, the verbal, the symbolic and the gestural modes of representations played their usual roles of visualization though they were not overtly so labeled. It should not be forgotten that the other traditional teaching methods, apart from those having a smack of visualization should also be given their due place in teaching.

The suggested changes in teaching should be taken to supplement the usual methods employed by the teacher to which all the parties involved are well accustomed to. The new should be mixed with old in a carefully selected proportion especially at the initial stages if the new is to gather its correct momentum gradually. For instance, if the teacher has been in the habit of dictating notes to the students and the mathematical problem solving, etc. to mention a few.

These ideas were given due consideration in planning the experiment in the manner described here. At the time, the experimental teaching started (May 2017), the grade 10 students had covered the two lesson topics in their first term in the schools

(January-March 2017). This ensured that the experimental and the control group both were exposed to the same customary teaching and learning practices in accordance with the teacher's guide. Further the control group was given the additional classes (experimental teaching) parallel to the experimental group using the same old teachers.

The significant gain of experimental group students (14%) show over the control group students and the experimental group students' positive feedback show that the new approach is capable of improving the students' physics performance. It is recommended that for other units of secondary school physics such as hydrostatics, electricity, waves, optics, electromagnetism, electronics, etc, it is worthwhile of applying the new approach.

References

1. Bodner, G. M., & Domin, D. S. (2000). Mental models: The role of representations in problem solving in chemistry. *Journal of Chemistry Education, 4(1)*, 24-30.
2. Buffler, A., Lubben, F., Ibrahim, B., & Pillay, S. (2008). A model-based framework for understanding the role of visualization in physics education. In *Proceedings of the 16th Annual Meeting of the Southern African Association for Research in Mathematics, Science and Technology Education, Maseru, Lesotho* (pp. 435-441).
3. Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies.* New York: Cambridge Univ. Press.
4. Department of Examinations Sri Lanka. (2009). *Evaluation Report, G.C.E. (O/L) Examination: 34-Science.* Department of Examinations, Battaramulla, Sri Lanka
5. Department of Examinations Sri Lanka. (2010). *Evaluation Report, G.C.E. (O/L) Examination: 34- Science.* Department of Examinations, Battaramulla, Sri Lanka
6. Department of Examinations Sri Lanka. (2011). *Evaluation Report, G.C.E. (O/L) Examination.* Department of Examinations: *34-Science*, Battaramulla, Sri Lanka
7. Department of Examinations Sri Lanka. (2012). *Evaluation Report, G.C.E. (O/L) Examination: 34-Science.* Department of Examinations, Battaramulla, Sri Lanka
8. Department of Examinations Sri Lanka. (2013). *Evaluation Report, G.C.E. (O/L) Examination: 34-Science.* Department of Examinations, Battaramulla, Sri Lanka
9. Department of Examinations Sri Lanka. (2014). *Evaluation Report, G.C.E. (O/L) Examination: 34-Science.* Department of Examinations, Battaramulla, Sri Lanka
10. Department of Examinations Sri Lanka. (2015). *Evaluation Report, G.C.E. (O/L) Examination: 34-Science.* Department of Examinations, Battaramulla, Sri Lanka
11. Evagorou, M., Erduran, S. & Mäntylä, T. (2015). The role of visual representations in scientific practices: from conceptual understanding and knowledge generation to 'seeing' how science works. *International Journal of STEM Education (2015)* 2:11
12. Gilbert, J. K. (2005). *"Visualization: A Metacognitive Skill in Science and Science Education."* In Visualization in Science Education, ed J K Gilbert, 9–27. Dordrecht, Netherlands: Springer.

13. Gilbert, J.K. (2010). The role of visual representations in the learning and teaching of science: An introduction. *Asia-Pacific Forum on Science Learning and Teaching*, *11(1)*, Foreword.
14. Hand, L. L., Uttal, D. H., Marulis, L., & Newcombe, N. S. (2008). *A meta-analysis of training effects on spatial skills*. Paper presented at the annual meetings of the Association for Psychological Science, Chicago.
15. Hill, M., Sharma, M. D., O'Byrne, J., &Airey, J. (2014). Developing and evaluating a survey for representational fluency in science. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, *22*(6).
16. Johnson-Laird, P N. 1998. Imagery, Visualization, and Thinking. In *Perception and Cognition at Century's End*, ed J Hochberg, 441–67. San Diego: Academic Press.
17. Johnstone, A. H. (1993) The Development of Chemistry Teaching A Changing Response to Changing Demand. *Journal of Chemical Education, 70* (9), 701-705.
18. Kohl, P. B., & Finkelstein, N. D. (2005). Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics-Physics Education Research*, *1*(1), 010104.
19. Kohl, P. B., & Finkelstein, N. D. (2006). Effects of representation on students solving physics problems: A fine-grained characterization. *Physical review special topics-Physics education research*, *2*(1), 010106.
20. Kozhevnikov, M., Motes, M.A., & Hegarty, M. (2007). Spatial Visualization in physics problem solving. *Cognitive Science, 31*, 549-579.
21. Kozma, R., & Russell, J. (2005). Students becoming chemists: Developing representational competence. In J. K. Gilbert (Ed.), *Visualization in science education* (pp. 121–145). Dordrecht: Springer.
22. Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, *56*, 1479-1498.doi:10.2307/1130467
23. Lyna & Fulmer, G.W. (2014). Secondary students' visual-spatial ability predicts performance on the Visual-Spatial Electricity and Electromagnetism Test (VSEEMT). *Science Education Review Letters,2014*, 8-21. Retrieved from http://edoc.hu-berlin.de/serl
24. McGee, M. G. (1979). *Human spatial abilities: Sources of sex differences*. New York, NY: Praeger
25. Mnguni, L.E. (2014).The theoretical cognitive process of visualization for science education. *SpringerPlus* 2014, 3:184 doi:10.1186/2193-1801-3-184
26. National Institute of Education, Sri Lanka (2015). *Grade 10 science teacher's guide,* Educational Publications Department of Sri Lanka.
27. Nieminen P., Savinainen A., Viiri J. (2017) Learning About Forces Using Multiple Representations. In: Treagust D., Duit R., Fischer H. (eds) Multiple Representations in Physics Education. Models and Modeling in Science Education, vol 10. Springer, Cham
28. Opfermann M., Schmeck A., Fischer H.E. (2017) Multiple Representations in Physics and Science Education – Why Should We Use Them?. In: Treagust D.,

Duit R., Fischer H. (eds) Multiple Representations in Physics Education. Models and Modeling in Science Education, vol 10. Springer, Cham

29. Paivio, A. (1986). *Mental Representations: A Dual Coding Approach Oxford*
30. Pallrand, G. J., & Seeber, F. (1984). Spatial ability and achievement in introductory physics. Journal of Research in Science Teaching, 21(5), 507-516.
31. Piaget, J., & Inhelder, B. (1956). *The child's concept of space*. Routledge & Paul
32. Piaget, J., & Inhelder, B. (1967). *The Child's conception of space*, W. W. Norton and Company, Inc: New York.
33. Pylyshyn, Z. W. 2003. *Seeing and Visualizing: It's Not What You Think.* Cambridge, Mass: MIT Press.
34. Rapp, D. N., & Kurby, C. A. (2008). The 'ins' and 'outs' of learning: Internal representations and external visualizations. In J. Gilbert, M. Reiner & M. Nakhleh (Eds.), *Visualization: Theory and Practice in Science Education* (3 ed., pp. 29-52): Springer Netherlands.
35. Reiner, M. (2008). Seeing through touch: The role of haptic information in visualization. In J. Gilbert, M. Reiner & M. Nakhleh (Eds.), *Visualization: Theory and Practice in Science Education* (3 ed., pp. 73-84): Springer Netherlands.
36. Sadoski, M, and A Paivio. 2001. *Imagery and Text: A Dual Coding Theory of Reading and Writing.* Mahwah, NJ: Erlbaum.
37. Santrock, J.W. (2009). *Educational psychology* (4^{th}ed.). McGraw-Hill: NY
38. Sekaran, U. & Bougie, R. (2013), *Research Methods for Business – A Skill Building Approach* (6^{th} ed.), John Wiley & Sons Inc, U.K
39. Shea, D. L., Lubinksi, D., & Benbow, C. P. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology*, *93*, 604-614. doi:10.1037//0022-0663.93.3.604.
40. Shu-Nu, C.-R., & Yao, B. J. (2014). *Visualization in research and science teachers' professional development*. *Asia-Pacific Forum on Science Learning and Teaching* (Vol. 15). Hong Kong Institute of Education. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kau:diva-43044
41. Sorby, S. A. (2000). Spatial abilities and their relationship to effective learning of 3-D solid modeling software. *Engineering Design Graphics Journal*, *64(3)*, 30-35.
42. Sorby, S. A., & Baartmans, B. J. (2000). The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students. *Journal of Engineering Education, 89(3)*, 301-307.
43. Stieff, M. (2011). Improving representational competence using molecular simulations embedded in inquiry activities. *Journal of Research in Science Teaching, 48*(10), 1137–1158.
44. Uttal, D. H., & O'Doherty, K. (2008). Comprehending and Learning from 'Visualizations': A Developmental Perspective: Models and Modeling in Science Education. In J. K. Gilbert, M. Reiner, & M. Nekhleh (Eds.), *Visualization: Theory and practice in science education: Models and Modeling in Science Education.* New York: Springer.

45. Uttal, D.H. & Cohen, C.A. (2012). Spatial thinking and STEM education: When, why, and how? , *Psychology of Learning and Motivation, 57*,147-181. DOI: 10.1016/B978-0-12-394293-7.00004-2
46. Vavra, K.L., Janjic-Watrich, V., Loerke, K., Phillips, L.M., Norris, S.P., &Macnab, J. (2011). Visualization in Science Education. *Alberta Science Education Journal, 41*(1), 22-30.
47. Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, *101*(4), 817.
48. Wiley, S. E. (1990). A hierarchy of visual learning. *Engineering Design Graphics Journal, 54(3)*, 30-35.
49. Wong C.L., Chu HE. (2017) The Conceptual Elements of Multiple Representations: A Study of Textbooks' Representations of Electric Current. In: Treagust D., Duit R., Fischer H. (eds) *Multiple Representations in Physics Education. Models and Modeling in Science Education*, vol 10. Springer, Cham
50. Yeo, J., & Gilbert, J. K. (2017). The Role of Representations in Students' Explanations of Four Phenomena in Physics: Dynamics, Thermal Physics, Electromagnetic Induction and Superposition. In *Multiple Representations in Physics Education* (pp. 255-287). Springer, Cham.