Comparison of Students' Learning and Attitudes in Physical versus Virtual Manipulatives using Inquiry-Based Instruction

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Abstract

This research aimed to determine whether implementation of virtual technology or implementation of physical materials in a learning environment is more efficient in understanding physics concepts and developing positive attitudes at the high school level. The theory that framed this study is the model of learning as dynamic transfer. Participants were 96 ninth grade students (*n* = 96) distributed randomly to the virtual or physical group. Inquiry-based instruction continued during teaching of kinematics and dynamics, which lasted for eight weeks for both groups. Data from the Force and Motion Achievement Instrument (FMAI), student worksheets, the Attitude Towards Physics Scale (APCS), and anecdotal observations were collected. This study concluded that the use of physical and virtual manipulatives in inquiry-based instruction had the same effect on students' conceptual and procedural knowledge, as well as their attitudes towards physics. However, students who dealt with physical experimentation had lower learning than their peers who experienced virtual experimentation due to measurement errors made by students. Furthermore, physical investigations left students with some irrelevant knowledge. Therefore, it is reasonable to assume that implementing virtual manipulatives is more advantageous for learning in some conditions. The final conclusion is that attitude and learning may be developed in a parallel manner.

Keywords: Attitude, learning, physics, physical manipulatives, virtual manipulatives

In an ideal situation, students are expected to formulate ideas that align with scientific explanations; however, significant constraints such as limitations of the laboratory environment work against this possibility (Marshall & Young, 2006). Educators should design the learning environment in a way that provides students with more experiences and more opportunities to understand the process of doing science so that it can facilitate learning (Vosniadou, Ioannides, Dimitrakopoulou & Papademetriou, 2001). Research suggests that laboratory and hands-on activities create effective learning environment to increase achievement in science knowledge and to influence attitudes toward science in a positive way when properly designed (Adesoji & Raimi, 2004; Freedman, 1997; Gibson & Chase, 2002). Both virtual and physical materials can be used during laboratory science activities for the construction of powerful learning environment.

Manipulatives are multisensory tools that represent ideas in more than one way to promote communication among students to enhance and deepen understanding (Shaw, 2002). De Jong, Linn and Zacharia (2013) stated that "both physical and virtual manipulatives can achieve similar objectives, such as exploring the nature of science, developing team work abilities, cultivating interest in science, promoting conceptual understanding, and developing inquiry skills, yet they also have specific affordances" (p. 305). The ability to change the values of variables and modify model characteristics (Ford & McCormack, 2000; Tao & Gunstone, 1999; Windschitl, 2000; Zacharia, 2003), make the "unseen" seen (Potkonjak et al., 2016), simplify complex and messy real-world models (Hennessy, Deaney & Ruthven, 2006; Hsu, 2008; Triona & Klahr, 2003; Trundle & Bell, 2010; Zacharia & de Jong, 2014), and conduct experiments about unobservable phenomena (Jaakkola, Nurmi & Veermans, 2011; Zacharia & Constantinou, 2008) are some of the advantages of using virtual manipulatives (VM). On the other hand, enabling learners to experience the challenges many scientists face (Balamuralithara & Woods, 2009; de Jong et al., 2013; Marshall & Young, 2006; Windschilt, 2000) and allowing them to acquire complexities and a sophisticated epistemology of science by dealing with unanticipated events and measurement errors (de Jong et al., 2013; Olympiou & Zacharia, 2012; Toth, Morrow & Ludvico, 2009) are some of the benefits of using physical manipulatives (PM).

Besides these pros, there are some cons of using virtual and physical manipulatives. Having obstacles for testing specific ideas and models in the micro-world (Roth, Woszczyna & Smith, 1996) and unfamiliar parameters (Marshall, 2002) are the constraints of virtual manipulative environment. Producing confusing and inconsistent feedback due to irrelevant information (Klahr, 2007) is the critical aspect of physical manipulative environment. Therefore, some researchers have found that VM enhance students' conceptual knowledge and attitudes of science more than PM. In contrast, other researchers have found the opposite effect. Due to the conflicting results in the literature, this research aimed to determine whether implementation of VM or PM in a learning environment is more efficient in understanding physics concepts and developing a positive attitude. In this context, the term virtual manipulative is used to refer to virtual technology such as computer-based simulations, videos, and e-books, whereas physical manipulative is used to refer to real-world concrete materials and instruments for this study. The research was interested in answering the following research question: What are the significance differences between using virtual manipulatives and physical manipulatives in terms of high school students' learning of motion and force concepts and their attitudes towards physics? One promising method of promoting conceptual change in science learning is inquiry-based learning (Hofstein & Lunetta 2004; de Jong 2006). However, inquiry learning is only effective if students receive sufficient instructional guidance (Alfieri et al., 2011; Driver et al., 1994). Therefore, guided inquiry-based instruction was preferred for the context of the study.

Theoretical Background

The importance of learning is that it is responsible for all the skills, knowledge, attitudes, and values that are acquired by human beings (Gagne, 1977). Thus, both knowledge and attitude are important outcomes of learning. Research in physics education has revealed that students in diverse grade levels hold various conceptions of mechanics that are irreconcilable with the Newtonian understanding of motion and force (Clement, 1982; Finegold & Gorsky, 1991; Graham, Berry & Rowlands, 2013; Mildenhall & Williams, 2001; Rowlands, Graham, Berry & McWilliam, 2007). On the other hand, attitudes of students towards science are leading us towards a society with less and less scientific vocation (Aguilera & Perales-Palacios, 2020). The educational challenge is to promote positive attitudes towards science, which should be given priority in educational research (Osborne, Simon & Collins, 2003).

Transfer is the dynamic creation of associations between knowledge elements (Rebello et al., 2005). Transfer occurs when students use learning from one context in another (Reed, 1993; Singley & Anderson, 1989). According to Schwartz, Varma and Martin (2008), because learners need to go beyond their original learning to accomplish a conceptual change, dynamic transfer occurs when component competencies are coordinated through interaction with the environment to yield novel concepts or material structures. In other words, students can learn from interacting with complex, well-structured environments that may include tools, representations, other people, and so forth (Schwartz et al., 2008). Schwartz and colleagues state that a model for dynamic transfer of learning also implies that learners need to bring their attitudes which help determine whether or not they will engage the environment in productive ways. Consequently, the theory that framed this study is the model of learning as dynamic transfer (diSessa & Wagner, 2005). This model deals with (re)constructing knowledge in new context or environment (Rebello et al., 2005). This model was chosen because the study examines students' physics learning and attitudes towards physics when interacting with a virtual or physical manipulative environment. According to Rebello et al. (2005), dynamic transfer occurs when instruction attempts to change student knowledge, provides rich setting for students to express themselves, and involves groups of up to three students.

Empirical Studies Comparing Virtual and Physical Manipulatives

Researchers have compared the impact of using VM and PM on learning and attitude by taking their affordances into consideration. Plenty of research has discovered cases where using VM seemed to be as effective for student learning and attitude as using PM (Apkan, 2002; Darrah et al., 2014; Jaakkola & Nurmi, 2008; Klahr, Triona & Williams, 2007; Taghavi & Colen, 2009; Triona & Klahr, 2003; Zacharia, 2003; Zacharia & Constantinou, 2008; Zacharia & de Jong, 2014; Zacharia & Olympiou, 2011). For example, Taghavi and Colen (2009) compared and evaluated the effectiveness of computer simulated laboratory instruction versus physical laboratory instruction. Their results based on 22 college students, indicated students' attitudes were similar with regard to both the simulated and physical laboratory instruction. Similarly, Zacharia and Constantinou (2008) explored the effect of experimenting with physical or virtual manipulatives on 68 undergraduate students' conceptual understanding of heat and temperature. Their results showed that both modes of experimentation were equally effective in enhancing students' conceptual understanding. Correspondingly, there are some studies revealing that the use of VM facilitated student learning more than the use of PM (Bozkurt & Sarikoc, 2008; Finkelstein et al., 2005; Husnaini & Chen, 2019; Wang & Tseng, 2018). For instance, Husnaini and Chen (2019) investigated the effects of physical and virtual laboratories on conceptual understanding of 68 secondary school students. The participants conducted a pendulum experiment with guided inquiry-based approach. The researchers discovered that the virtual laboratory was more effective for improving difficult concepts than the physical laboratory. On the other hand, a few research studies produced opposite results, where PM created a more valuable experience than VM (Coramik, 2012; Marshall & Young, 2006). Marshall and Young (2006) studied three prospective teachers, working together in a group, as they used both Interactive Physics and physical manipulatives to explore what happens to the momentum of objects in collisions. According to their results, the participants took longer to execute cycles of exploration with the computer than with the physical manipulatives. Furthermore, they spent much more time processing feedback from the program. It is important to ask why the results of plenty of research mentioned above are not consistent with each other. The reason for the discrepancies may be that some variables such as instructional method, teacher's approach, and physical conditions were not taken under control in most of the studies. Since these factors directly affect student learning and attitude, it is hard to reach any consensus about which manipulative, physical or virtual, is better to use. More quasi-experimental studies are needed.

Reviewing the literature also points out that the majority of research was conducted with university students. Research carried out with high school students is rare. In addition, comparisons of the impact of using VM and PM on learning has been made for various physics concepts but little research has focused on motion and force concepts. This is critical because it is important to study students' conceptual understanding across several science domains (Olympiou & Zacharia, 2012). Much remains to be learned about the relative efficacy of physical and virtual materials when they are used in different science domains, with different instructional goals, approaches, outcome measures, and types of students (Klahr et al., 2007). Besides, studies comparing the effectiveness of virtual and physical experiments on different outcomes other than learning are worthy of investigation (de Jong et al., 2013). Therefore, the purpose of the present study was to compare the impact of using virtual manipulatives and physical manipulatives on students' learning of motion and force concepts and their attitudes towards physics.

Methodology

Participants

A pre–post comparison design was used for this research. Participants were randomly assigned to a virtual manipulative group or a physical manipulative group. The participants were 96 ninth graders (*n* = 96) from an all-boys military boarding school. They were already randomly distributed to four classes by the school administration. Consequently, there were 24 students in each class. The students' ages were between 15 and 16. One author was the physics teacher for the four classes and he randomly chose two classes to work with the virtual manipulatives. The other two classes worked with the physical manipulatives. In total, there were 48 students in each group.

Procedure

The research was conducted in the students' physics class. The students attended the class two hours a week. The instruction took place during a chapter on motion and force, which lasted eight weeks. This chapter included the following concepts: position, distance, displacement, speed, velocity, instant velocity, average velocity, acceleration, force, force of friction, weight, Newton's first law of motion (law of inertia), Newton' second law of motion, and Newton' third law of motion (action-reaction forces). The fact that there were various teaching resources related to one dimensional motion and force enabled the teacher to use different manipulatives.

The participants had formal education on motion and force concepts when they were students in the middle school.

Since the participants came to this boarding school from various middle schools and might have different backgrounds about inquiry, guided inquiry was employed in both groups to enable students who lacked experience to conduct research and experiments. During the guided-inquiry instruction, the problem, the background, and guidance of the procedures were given to the students but the methods of analysis, interpretation, and conclusion were for the students to generate. The same concepts were taught and same sample problems were solved in both virtual and physical manipulatives groups. The students were actively involved in exploring and constructing their own understanding and worked in groups where it was necessary to enable occurrence of dynamic transfer.

Activities in the groups started with open-ended questions to assess the students' prior knowledge and capture their attention. The students worked collaboratively in small groups and were encouraged to state their ideas in discussions held at the end of the activities. Sometimes the teachers addressed misunderstandings with the help of student explanations. Learning objectives, instructional method (inquiry), time on task, types of questions and probes from the teacher and assessment were the same for both the virtual and physical groups. The participants took their classes in the same technology-supported physics laboratory and their teacher was the same person. Moreover, since the participants were semester boarders, their learning activities after school hours were pretty much the same. Therefore, important variables that might influence learning and attitude were the same for the groups. Only the medium of presentation – virtual or physical – varied between the groups. Simulations, video recordings, interactive whiteboard, tablets and z-book were used in the virtual manipulatives group; while, experiment sets including air track, board and textbooks were used in the physical manipulatives group. For example, for students to learn position, displacement, speed, and velocity concepts, the students ran "walking man" simulation, the teacher used interactive presentations, and the teacher and the students solved some problems on the smart board by using interactive programs in the VM group. Meanwhile, the students did experiments with air tracks, the teacher made explanations by using the board, and the teacher and the students solved some problems on the board interactively to facilitate student learning of these concepts in the PM group. Likewise, the students in the VM group used a 2D freeware program and played the "maze game" online while the students in the PM group used air track sets and did hands-on activities by playing with velocity and acceleration cards to learn about acceleration.

The inventories designed to measure student learning and attitude were administered to the participants in four classes at the same time as pre- and post-tests. Other teachers in the school were observers and the researcher visited the classes during the administration.

The students were given worksheets created by the researchers that helped them explore scientific knowledge by requesting and guiding them to construct experiments and conduct various measurements. They included open-ended questions to get students' attention. Thus, six worksheets were prepared throughout the motion and force chapter based on the same performance objectives. The only difference between the worksheets used in both groups was the manipulatives in the directions and questions. The concepts and performance objectives assessed in the worksheets are presented in Table 1. The worksheets were completed by the students individually.

Table 1
Concepts and Performance Objectives Assessed in the Worksheets

Worksheet	Concepts	Performance Objectives
1	Linear motion	Collecting data by doing experiments, drawing of position-time and velocity-time graphs, interpretation of graphs, graph transformations.
2	Acceleration and two dimensional motion.	Explanation of acceleration by relating it with speeding up and slowing down. Inquiring the reasons for acceleration, collecting data by doing experiments, drawing of velocity-time and acceleration-time graphs, interpretation of graphs, graph transformations.
3	Force and friction force	Explanation of friction force, comparison of static and kinetic friction forces, exploring variables that the friction force depends on, making inferences from data, exploring advantages and disadvantages of friction force in daily life.
4	Balanced forces and Newton's first law	Calculation of the combination forces exerted on an object and explanation of motion of the object. Exploring and explaining of Newton's first law related to inertia by collecting data and doing experiments.
5	Newton's second law	Exploring and explaining of Newton's second law by collecting data and doing experiments.
6	Newton's third law	Exploring and showing action and reaction forces by using free-body diagrams.

Role of the Researcher and Teacher Intervention

The teacher of both groups was the first author. He had two roles. One role was as the participants' teacher and the other was as a researcher, who collected and analyzed the data. However, he was only a teacher throughout the instruction of motion and force concepts. He did not analyze any data until the instruction was over. Due to his teacher role, he established good communication with the students and worked to create an environment where the students felt comfortable about sharing their views. Rebello et al. (2005) argue that the researcher should be an observer and an instructor in order for dynamic transfer to occur. Therefore, he observed the students, directed them to the next step and promoted learning with the manipulatives.

Even though the teacher did not adopt the researcher role during instruction, some precautions were taken in order to prevent possible researcher bias. First, the two researchers prepared the lesson plans and worksheets together for both groups. This was an effort to make sure that the only difference between the groups was the manipulatives. Second, each lesson in both groups was videotaped and the two researchers watched and discussed the teacher's acts and performances before the next lesson to prevent any action that might affect student learning apart from the instruction. There was not any threat identified in the video recordings regarding research bias. Third, all of the data collection sources were written documents and both researchers analyzed them together. And finally, interrater reliability values were measured for the scoring of the rubrics.

Data Collection

The empirical phase of the study included the eight weeks of instruction, as well as two weeks for pre- and post-tests. In total, the study lasted ten weeks. As described below, both qualitative and quantitative methods were used to collect data.

Participant learning. Student learning was assessed formatively as well as summatively. In order to measure changes in student understanding of kinematics and dynamics concepts, the Force and Motion Achievement Instrument (FMAI) developed by Gokalp (2011) was administered as a pre-test and a post-test. This instrument was chosen among similar instruments for multiple reasons. First, it was comprehensive and specifically designed for ninth grade students. Second, the FMAI assessed both content and skill objectives by using various types of questions. Finally, the internal reliability coefficient for the FMAI was reported as .84 (Gokalp, 2011), which indicates high internal reliability. After performing both exploratory factor analysis and confirmatory factor analysis, Gokalp (2011) found that the FMAI measured students' achievements of "uniform linear motion", "fundamental forces", "Newton's laws of motion", "friction", and skill objectives as intended. Skill objectives were related with problem solving skills, information and communication technology skills, and physics-technology-society-environment skills. The instrument itself consisted of 30 questions including 16 multiple-choice, 12 open-ended, and two true-false questions. The questions on the instrument were conceptual as well as quantitative. Each question in the FMAI has an option of "I don't know / I can't do". In this way, unanswered questions can be categorized accurately. If this option was chosen, it was coded as "0". The true-false and multiple-choice questions were coded as "0" for nonscientific answers and "1" for scientific answers. There was a scoring rubric to analyze students' answers. The open-ended questions were coded as "0" for nonscientific answers, "1" for partially scientific answers, "2" for mostly scientific answers, and "3" for totally scientific answers. Therefore, possible scores ranged from 0 to 54. Students were given 50 minutes to complete the FMAI. Two open-ended questions and their scoring rubric were given. See the Appendix for examples.

Based on Rebello et al.'s (2005) suggestion for dynamic learning, student learning was also assessed during the instruction with the help of worksheets. Formative assessment integrated with instruction ideally provides a seamless process of assessment followed by instruction (Cauley & McMillan, 2010). Thus, the worksheets were used for the purpose of assessment for learning. The students completed each worksheet in one class hour. Student learning of the concepts covered during instruction was compared in detail. One two-point scoring rubric (from 0 to 2) was created for each worksheet based on the performance objectives assessed in the worksheet. As a result, six scoring rubrics were generated in total. The rubrics were the same for both groups.

Participant attitude. Changes in student attitude towards physics was assessed by applying the Attitude Towards Physics Scale (APCS) developed by Geban et al. (1994). This instrument was administered before and after the instruction. The instrument consisted of 15 items and a 5-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"). Possible scores on the APCS ranged from 15 to 75. Four items were related to enjoying physics, seven items were about interest in physics, and four items were related to necessity of physics. The internal reliability coefficient for the APCS was 0.83. This scale was chosen to because of its high internal reliability and shortness.

In addition to the FMAI, the APCS, and the worksheets, anecdotal observations were recorded while the students were working with manipulatives.

Data Analysis

Normality analyses were done separately for the learning and attitudinal data. Shapiro-Wilk tests were performed to determine if the pre- and post-tests data gathered from the APCS and the FMAI were normal. The significance values for pre-FMAI, post-FMAI, pre-APCS, and post-APCS were greater than 0.05 ($p = 0.11$, $p = 0.50$, $p = 0.22$, $p = 0.55$ respectively); therefore, all data followed normal distributions within a 95% confidence interval. Skewness and kurtosis were also calculated. Skewness values were between -1.0 and -0.5. Values of kurtosis fell between 0.5 and 1.0. Therefore, they supported normality. Independent *t*-tests were performed to analyze the data and compare the groups statistically. Dependent *t*-tests were used to analyze the data within groups. Effect sizes were calculated for the changes in the groups (Cohen, 1988).

The reliability analyses of the FMAT and the APCS were performed for this study. The worksheets were evaluated by one of the researchers based on the rubrics. In order to assess the reliability of scoring, the other researcher randomly selected 32 students (30%) from the PM and VM groups and scored their worksheets independently. Then, the two researchers compared their scoring and calculated the agreement for each group of worksheets separately. The researchers were able to reach 91% agreement for the first worksheet. The reliability measured by Cohen's κ was 0.71. Agreement percentages for the remaining five worksheets were 96%, 94%, 91%, 92%, and 93%. The following Cohen's κ values were reached regarding these agreement values: 0.86, 0.85, 0.70, 0.80, and 0.80. Fleiss (1981) characterizes Kappa values over 0.75 as excellent, values between 0.40 to 0.75 as fair to good, and below 0.40 as poor. Consequently, the scoring of students' knowledge reflected in the worksheets had adequate reliability. The authors re-scored the items on the rubrics that did not have initial agreement and the final scoring scheme was constructed by reaching consensus.

Results

Results of Student Learning

The internal reliability coefficient for the pre-FMAI was 0.40 indicating low reliability and 0.67 for the post-FMAI indicating medium reliability. Some students might have forgotten some parts of the force and motion domain after several years.

The results of independent samples *t*-tests showed a small difference between the two groups' performance on the FMAI (see Table 2). Before instruction, the physical manipulative group scored slightly higher (*M* = 12.16, *SD* = 3.30) than the virtual manipulative group (*M* = 11.77, *SD* = 3.74), a difference that was not statistically different. After instruction, the physical manipulative group scored lower on the FMAI (*M* = 27.20, *SD* = 4.81) compared to the virtual manipulative group (*M* = 27.56, *SD* = 5.81). Again, this difference was not statistically significant.

Table 2
Comparison of the FMAI Scores Between Groups

	Group	*M* (*SD*)	t	df	p
Pretest	PM	12.16 (3.30)	-0.51	85	.608
	VM	11.77 (3.74)			
Posttest	PM	27.20 (4.81)	0.31	87	.757
	VM	27.56 (5.81)			

However, the results of paired samples *t*-tests specified that both the PM and VM groups' post-instruction FMAI scores were significantly higher than their pre-instruction FMAI scores (see Table 3). There was an increase in the VM group's FMAI scores from pre-instruction to post-instruction ($M_{pre\text{-}post} = -15.79$) and the pre-to-post difference was statically significant for the VM group: $t_{(75)} = -15.28$, $p < .001$. The PM groups' FMAI scores also increased from pre-instruction to post-instruction ($M_{pre\text{-}post} = -15.04$), a difference that was statically significant: $t_{(75)} = -17.05$, $p < .001$. The increase in performances from pre-instruction to post-instruction was little higher for the VM group than for the PM group. Effect sizes between the pre- and the post-instruction FMAI scores were found to be 0.88 for the PM group and 0.85 for the VM group, which exceeded Cohen's (1988) convention for a large effect ($d = 0.80$).

Table 3
Comparison of the FMAI Scores Within groups

Group	Measurement	Mean Difference	*t*	*df*	*p*
PM	Pretest-posttest	-15.04	-17.05*	76	.000
VM	Pretest-posttest	-15.79	-15.28*	75	.000

The worksheets used as for formative assessment enabled the researchers to compare student understanding while they were working on the experiments and utilizing the manipulatives. Table 4 presents the results of independent samples *t*-tests for the groups' learning as assessed by the worksheets.

Table 4
Comparison of Worksheet Scores Between the Groups

Subject	Group	*M* (SD)	*t*	*df*	*p*
Linear Motion	PM	1.08 (0.11)	13.90	79	.000**
	VM	1.53 (0.17)			
Acceleration and two-dimensional motion	PM	1.56 (0.29)	2.58	51	.013*
	VM	1.69 (0.13)			
Force and friction forces	PM	1.42 (0.15)	0.94	69	.349
	VM	1.46 (0.21)			
Balanced forces and Newton's first law	PM	1.70 (0.23)	-1.71	75	.092
	VM	1.59 (0.35)			
Newton's second law	PM	1.61 (0.26)	2.14	40	.038*
	VM	1.71 (0.11)			
Newton's third law	PM	0.96 (0.52)	2.46	73	.016*
	VM	1.24 (0.47)			

* p < .05, ** p < .001

As shown in Table 4, the mean linear motion score on the rubric earned by the VM group ($M_{VM} = 1.53$, $SD = 0.17$) was higher than the PM group ($M_{PM} = 1.08$, $SD = 0.11$). This difference was statistically significant, $t_{(79)} = 13.90$, $p < .001$. The same situation occurred for acceleration and two-dimensional motion. That is, the mean acceleration and two-dimensional motion score on the rubric earned by the VM group ($M_{VM} = 1.69$, $SD = 0.13$) was higher than the PM group ($M_{PM} = 1.56$, $SD = 0.29$). This difference was statistically significant, $t_{(51)} = 2.58$, $p < .05$. Similarly, the mean Newton's second law score on the rubric earned by the VM group ($M_{VM} =$

1.71, *SD* = 0.11) was higher than the PM group (M_{PM} = 1.61, *SD* = 0.26). This difference was statistically significant, $t_{(40)} = 2.14$, $p < .05$. Finally, the mean Newton's third law score on the rubric earned by the VM group (M_{VM} = 1.24, *SD* = 0.47) was higher than the PM group (M_{PM} = 0.96, *SD* = 0.52). This difference was statistically significant, $t_{(73)} = 2.46$, $p < .05$.

Students in both groups studied linear motion by drawing position-time and velocity-time graphs, which was covered during instruction. Whereas the VM group could draw graphs on the simulations, the PM group collected data from the air track set and drew graphs on graph papers. However, according to anecdotal observations, some students in the PM group wrote time values on the vertical displacement axis instead of horizontal axis; hence, they did not draw proper constant velocity-time graphs. As a result, they might not understand the meaning of linear motion. While studying non-uniform motion, some students in the PM group could not calculate the slope of the velocity-time graph correctly. In addition, they could not draw the acceleration-time graph. This might be one of the reasons they could not conceptualize what happened if the velocity of an object was not constant and the object was speeding up or slowing down. As seen in Table 4, the mean rubric scores for the concept of acceleration were higher than the mean scores for linear motion in both groups. After working on the graphs during the application of the first worksheet, the students' graph skills increased by the second worksheet, resulting in more scientific graphs related to motion. Simulations that were used by the students in the VM group provided visualizations for the concepts of acceleration and force. This situation might have enabled students to acquire more knowledge of Newton's Second Law.

While students in the PM group were doing experiments and filling in the last worksheet about Newton's Third Law, two students connected two dynamometers to the glider improperly (opposite directions). Then, one student held one dynamometer steady whereas another student pulled the other dynamometer. They read the values on the dynamometers and recorded them, repeating this experiment three times. One student measured forces of 1.5N, 1.0N, and 2.0N, and the other student measured forces as 1.3N, 0.9N, and 1.8N respectively. Since the forces were in opposite directions and the force values were different, some students got confused and thought the glider had to move. Moreover, some students claimed that there was extra force due to the object's weight. Some students did not reset the dynamometer before starting to take new measurement and some of them could not hold it properly. At the end, these students in the PM group had difficulty making the inference that action and reaction forces are equal and opposite forces that act on different objects. That is the PM might have generated a little confusion and was not helpful for students to understand Newton's third law. Additionally, the students in the VM group did not encounter any measurement error while doing the experiments because the simulations showed numerical values of the parameters they used. Simulations provided students immediate feedback about the effect of the changes they made (Olympiou & Zacharia, 2012). This might have allowed them to investigate cause-and-effect relationships and answer questions in the worksheets more scientifically.

There was no statistical difference between the groups' learning of force and friction during instruction (M_{PM} = 1.42, *SD* = 0.15; M_{VM} = 1.46, *SD* = 0.21). Students in both groups were familiar with these concepts from the middle school science curriculum. As a result, implementing these concepts by using virtual or physical manipulatives might not have made a difference in their learning. From the dynamic transfer perspective, Schwartz et al. (2008) explained this learning situation as conceivable extension, which does not have to constitute a conceptual change alone. Although there was not a significant difference, the mean value of the PM group was higher than the mean value of the VM group for the fourth worksheet, whose performance objective was related to Newton's first law ($M_{PM} = 1.70$, $SD = 0.23$; $M_{VM} = 1.59$, $SD = 0.35$). Experiencing inertia physically and concretely during the lab activities might make it more plausible for students.

Informal observations revealed that the students in the PM group asked more questions to their teacher in order to do the experiments. At times they could not grasp exactly what to do. Hatano and Inagaki (1986) argued that if the risk attached to the performance of a procedure is minimal, people are more inclined to experiment and adapt new ways of doing things. The students in the PM group might have felt some distress while taking measurements and dealing with errors. This situation might have prevented them from acquiring new knowledge easily. Nevertheless, the students in the VM group could reach their goals after a few attempts within the simulations. They seemed more curious and involved with the lessons. Since these students are Generation Z learners and are more equipped with technology (Cilliers, 2017; Turner, 2015), they might be more open to learning with virtual manipulatives. These reasons might help explain the differences in the students' performances as assessed by the worksheets.

Results of Students' Attitude

Cronbach's alpha values for the pre- and post-instruction APCS were 0.90 and 0.93 respectively, indicating high reliability. As presented in Table 5, the results of independent samples *t*-tests showed there was no significant difference between the PM group's attitude ($M = 49.09$, $SD = 9.70$) and the VM group's attitude towards physics ($M = 47.57$, $SD = 9.89$) before the instruction. Furthermore, there was no significant difference between the groups' attitude towards physics after the instruction ($M_{PM} = 56.45$, $SD = 7.80$ vs. $M_{VM} = 54.72$, $SD = 8.57$).

On the other hand, the results of paired samples *t*-tests for the groups' attitude towards physics (see Table 6) revealed that both PM group ($M_{PMpre\text{-}post} = -7.36$), $t_{(88)} = -3.98$, $p < .001$) and VM group ($M_{VMpre\text{-}post} = -7.15$), $t_{(85)} = -3.60$, $p < .001$) significantly developed more positive attitudes after they received instruction with manipulatives. Effect sizes between the pre- and the post-instruction APCS scores were 0.38 for the PM group and 0.36 for the VM group. Both values were above Cohen's (1988) convention for a small effect ($d = 0.20$).

Table 5
Comparison of APCS Scores Between Groups

	Group	*M* (SD)	*t*	*df*	*p*
Pretest	PM	49.09 (9.70)	-0.73*	85	.470
	VM	47.57 (9.89)			
Posttest	PM	56.45 (7.80)	-1.00*	88	.320
	VM	54.72 (8.57)			

Table 6
Comparison of APCS Scores within Group

Group	Measurement	Mean Difference	*t*	*df*	*p*
PM	Pretest-posttest	-7.36	-3.98**	88	.000
VM	Pretest-posttest	-7.15	-3.60**	85	.000

**p < 0.01

Discussion

In this study, the aim was to compare the effects of using PM and VM within a guided inquiry approach on student outcomes. Student outcomes were analyzed on two levels: knowledge acquisition and attitude. The students worked with their peers during the experiments. Every tool utilized in the VM group was virtual including books and the board. Conditions of dynamic transfer of learning were tried to accomplish during the instruction by providing a learning environment where the students expressed themselves and worked as groups and the instructor observed them and used real-time assessment.

The comparisons made between the PM and VM groups as well as within each group in term of the FMAI scores before and after instruction revealed student learning was the same regardless of whether they were instructed with PM or VM. In other words, the students' selection of scientific choices and their scientific explanations for the content and skill questions on the FMAI were similar. These findings point out that the students' learning of force and motion concepts was elevated and they learned almost equally with either manipulation. This result was in line with findings from other scholars (Darrah et al., 2014; Jaakkola & Nurmi, 2008; Klahr et al., 2007; Triona & Klahr, 2003; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011). However, the present study was the only study whose participants were high school students learning about the subject of motion and force.

The students who were taught dynamics concepts by using virtual manipulatives understood more concepts than the students who were taught dynamics concepts by using physical manipulatives during the instruction. This result was similar with previous research (Finkelstein et al., 2005; Husnaini & Chen, 2019) whose participants ranged from secondary school students to undergraduate students and involved an inquiry-based context. However, the findings divulged by Coramik (2012) and Marshall and Young (2006) contrast the results of this study. In Coramik (2012)'s research, the participants did not do their experiments by implementing inquiry-based approach. Therefore, his context was different from this study's context. The participants of Marshall and Young (2006), on the other hand, were not the students, they were teachers. Therefore, different context and different group of participants might result the inconsistency between this research and those.

Attitudes are tenacious over time (Hill, Atwater, & Wiggins, 1995; Koballa, 1988). Since the participants were ninth graders and took physics for the first time, the eight-week duration was enough for students in both groups to change their attitudes. Neither instruction supported with VM or PM displayed superiority. They had the same influence on the students' attitude toward physics. This result was consistent with findings that have emerged from research done by Taghavi and Colen (2009) who revealed that college students' attitudes were similar with regard to both simulated and physical laboratory instruction. The students' attitudes towards science increased no matter which manipulatives were used during the instruction.

Research implies that hands-on activities, cooperative learning, and student involvement in learning had strong influences on attitude toward science (Zacharia, 2003). In addition, Lee et al. (2020) stated that students who viewed experimental learning as achieving in-depth understanding and who perceived that experiments were guided by clear rules were prone to express a stronger sense of academic self-efficacy. The students in both groups worked in groups and followed the instructions in the worksheets as a part of the inquiry approach while they were learning. These might be the reasons that the students in the PM group as well as the VM group developed more positive attitudes towards physics.

Conclusions and Suggestions

Dynamic transfer can create conceptual change (diSessa & Wagner, 2005). Dynamic transfer depends on the environment to support coordination because it is the product of a sequence of interactions with a well-structured environment that may include tools, representations, other people, and so forth (Schwartz et al., 2008). Guided participation is based on the belief that students are active learners and the learning environment is integral to the learning process (Rogoff, 2003).

This study concludes that use of PM and VM in inquiry-based science has the same effect on students' conceptual and procedural knowledge, as well as their attitude towards physics. Interactions with the environment generate feedback and variability that can help students shake free of their initial interpretations and extend their knowledge (Schwartz et al., 2008). Learning environments including either VM or PM can facilitate conceptual change and dynamic transfer related to motion and force concepts.

The second conclusion is that due to measurement errors, learning of students who deal with physical experimentation is lower than learning of their peers who use virtual experimentation. Differences between formative and summative assessment results revealed that students in PM group may need time to internalize their understanding because they first resolved the problems created by measurement errors. Furthermore, physical investigations leave students with some irrelevant knowledge. Nonetheless, students in PM group were able to transfer their knowledge and use their learning gains after the instruction. An environment including virtual technology does not allow errors and this situation may maximize, as Greeno Moore and Smith (1993) elucidate, the possibilities of students' attunement to the affordances of tools. Experimenting with VM helps students grasp the motion-force relationship and understand of graphs quickly. Hence, VM can be implemented to provide authentic experiences (Steinberg, 2000) and encourage learning. Finally, although researchers have tried to explain whether attitudes influence learning or if learning influences attitudes (Zacharia, 2003), this study concludes that attitude and learning may be developed in parallel because both increased at the end of the instruction.

This study has several implications. The conclusions suggest that physical and virtual manipulatives can be used for one another when inquiry-based learning is emphasized. It is reasonable to assume that implementing virtual manipulatives has even more advantages on learning in some conditions. This suggestion is important for the science education community, especially regarding virtual schooling that came along with the recent global pandemic. However, students need to learn how to do error analysis in order to experience science phenomena in the real world; thus, using physical materials should not be abandoned. This study adds to current science education literature by using virtual materials in one group and demonstrating the effects of comparing virtual and physical materials on students' attitude and learning of motion and force concepts. Teachers might consider struggles and easiness that the students came across while dealing with virtual and physical manipulatives during this study and plan their teaching in a way that their students avoid the same struggles and experience the same easiness. Researchers would conduct exploratory studies that examine how students learn with the help of virtual and physical manipulatives.

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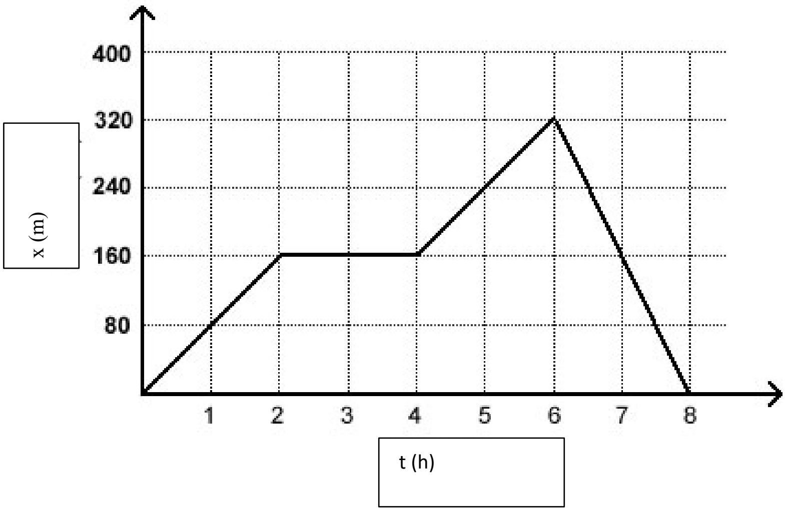
APPENDIX

Question 23



A car's position-time graph is presented above. Please describe and explain the car's motion in two hour-time interval within 8 hours by using numerical values.

Fully compatible with scientific knowledge (3 points):

The car moved in uniform linear motion and displaced 160 km with 80 km/h velocity in the first two hours. The car stopped and did not change its position for the time interval from 2 hours to 4 hours. The car started to move in uniform linear motion again with 80 km/h velocity and displaced 160 km for the time interval from 4 hours to 6 hours. The car went back to its first position by moving in opposite direction in uniform linear motion with 160 km/h velocity and displaced 320 km.

Mostly compatible with scientific knowledge (2 points):

- Answers describing and explaining the car's motion correctly in three time intervals or
- Answers describing the car's whole motion correctly without using numbers (for example the car moved in uniform linear motion in the first two hours but did not move for the next two hours).

Partially compatible with scientific knowledge (1 point):

- Answers describing and explaining the car's motion correctly in two or less time intervals or
- Answers describing the car's some part of motion correctly without using numbers.

Nonscientific knowledge (0 point):

Answers that do not include any correct information about the car's motion.

Question 29

Design an experiment to investigate the differences between static and kinetic friction forces.

Fully compatible with scientific knowledge (3 points):

Any experiment design that enables to measure and compare an object's frictional force before and after its motion

Mostly compatible with scientific knowledge (2 points):

Although there is a complete design, some measurements cannot be taken.

Partially compatible with scientific knowledge (1 point):

Design is incomplete and some measurements cannot be taken.

Nonscientific knowledge (0 point):

All the other circumstances that do not match with the answers above.