Eurasia Journal of Mathematics, Science & Technology Education, 2015, **11**(5), 1119-1140

Comparing the Impact of Dynamic and Static Media on Students' Learning of One-Dimensional Kinematics

Vanes Mešić
University of Sarajevo, BOSNIA AND HERZEGOVINA
Dževdeta Dervić
Second Gymnasium Sarajevo BOSNIA AND HERZEGOVINA
Azra Gazibegović-Busuladžić & Džana Salibašić
University of Sarajevo, BOSNIA AND HERZEGOVINA
Nataša Erceg
University of Rijeka, CROATIA

•*Received 30 January 2015*•*Revised 29 March 2015* •*Accepted 15 April 2015*

In our study, we aimed to compare the impact of simulations, sequences of printed simulation frames and conventional static diagrams on the understanding of students with regard to the one-dimensional kinematics. Our student sample consisted of three classes of middle years students (N=63; mostly 15 year-olds). These three classes served as comparison groups in our pre-post quasi-experiment, whereby each of them was assigned to one of the experimental treatments, i.e. media types. The results of the ANCOVA showed that students who learned from simulations or from printed sequences of simulation frames significantly outperformed their peers who had learned one-dimensional kinematics from conventional static diagrams. Thereby, we have found that learning from sequences of simulation frames seems to be particularly effective for girls. The use of simulations or printed simulation frames has also proved to be associated with more positive attitudes of students towards kinematics instruction.

Keywords: learning media, simulations, gender differences, kinematics

INTRODUCTION

Many educators and researchers agree to the point that mechanics has a special place amongst other domains of introductory physics. As a matter of fact, Carson and Rowlands (2005) consider mechanics to be a "logical point of entry for the enculturation into scientific thinking" (p. 476) whose understanding is essential for understanding physics as a whole. Similarly, Galili (1995) points out that mechanics defines the main tools in physics and describes its method which justifies the practice of opening physics curricula with the study of mechanics.

In practice, one-dimensional kinematics is the sub-domain of mechanics which

Correspondence: Vanes Mešić,
Faculty of Science, University of Sarajevo, Zmaja od Bosne 35, 71 000 Sarajevo, Bosnia and Herzegovina.
E-mail: vanes.mesic@gmail.com
doi: 10.12973/eurasia.2015.1385a

ISSN: 1305-8223

often serves as a starting point for "*enculturation into scientific thinking*". According to Trudel and Metioui (2011), the acquisition of basic kinematic concepts is a precondition for learning mechanics and the study of kinematics provides a good context for developing important scientific skills such as performing measurements, systematic collection of data and creating graphs. As a matter of fact, the ability to create and interpret graphs is often considered to be one of the most important skills in and beyond physics (Beichner, 1994; McDermott, Rosenquist & van Zee, 1987).

Taking into account the striking importance of kinematics knowledge for understanding physics as a whole, it is not surprising that since early 1980s there has been a considerable amount of research related to the students' learning of kinematical concepts and the acquisition of graphing skills (e.g. Trowbridge & McDermott, 1980; Trowbridge & McDermott, 1981; Halloun & Hestenes, 1985; McDermott, Rosenquist & van Zee, 1987; Aguirre, 1988; Planinic, Ivanjek, Susac & Milin-Sipus, 2013; Erceg & Aviani, 2014).

The results of the studies suggest that students often exhibit significant difficulties in acquiring the concepts of velocity (Trowbridge & McDermott, 1980), acceleration (Trowbridge & McDermott, 1981) and reference frames (Aguirre, 1988) as well as difficulties in creating and using graphs (McDermott, Rosenquist & van Zee, 1987; Beichner, 1994).

When speaking about conceptual barriers for developing students' understanding of kinematics, researchers point out terminological (Knight, 2004; Reif, 2010), intrinsically cognitive (Knight, 2004; Arons, 1997) and didaktikogenic factors (Arons, 1997) as well as the factor of foreknowledge of relevant mathematical concepts and skills (Lichtenberger, Vaterlaus & Wagner, 2014).

State of the literature

- The results of psychological studies on the relative effectiveness of using simulations versus static images for learning about mechanical systems are inconsistent.
- There is some evidence from psychological research stating that using temporal sequences of static images could be the most effective way for learning about mechanical systems.
- In the physics education literature, there are only a few studies regarding the effectiveness of using simulations for teaching kinematics. Some of these studies suggest that simulations can be as effective as microcomputer-based laboratories. Generally, students' attitudes towards simulations are reported to be positive.

Contribution of this paper to the literature

- This is the first study on the effectiveness of using sequences of simulation frames for teaching/learning kinematics in authentic school contexts. It seems that using sequences of simulation frames can be a promising approach for closing the gender gap in kinematics education.
- The effects of using different media types are studied from multiple perspectives, i.e. effects on understanding, ability of far transfer and attitudes.
- Within the process of test construction the importance of students' ability to use multiple representations (graphs, stroboscopic diagrams, verbal and tabular representations) has been acknowledged.

In order to facilitate the development of students' conceptual understanding of basic kinematics knowledge, scholars have suggested numerous approaches for reforming the traditional kinematics curriculum (McDermott, Rosenquist & van Zee, 1987; Thornton & Sokoloff, 1990; Beichner, 1996; Pena & Alessi, 1999; Ploetzner, Lippitsch, Galmbacher, Heuer, & Scherrer, 2009). Common to most of these approaches is the idea that students should engage in activities of observing motion of objects, measuring their positions and interpreting the object's motion in different representations. Thereby, it is particularly important for the students to develop the ability of translating between abstract conceptual representations of kinematical concepts and real world representations of the object's motion. These learning activities can be effectively implemented by appropriate use of modern educational technologies, such as: micro-computer based laboratories (Thornton & Sokoloff, 1990), digital video analysis (Beichner, 1996) and computer simulations (Pena & Alessi, 1999; Jimoyiannis & Komis, 2001).

Pena and Alessi (1999) compared the impact of two instructional strategies (augmented activation activities versus expository instruction) and three presentational formats (micro-computer based laboratory, simulation and computer based text) on students' understanding of free fall. Thereby, they came to the conclusion that simulations were as effective as micro-computer based laboratories (MBLs) and both these approaches were more effective than computer based texts.

In the area of psychology, a considerable amount of research has been conducted related to the relative efficacy of using different media in teaching about mechanisms and physical systems (Hegarty, 2014). Thereby, previous research mostly failed to produce consistent effects favoring either dynamic (animations) or static media (still images). As a matter of fact, the results of the study by Mayer, Hegarty, Mayer and Campbell (2005) suggest that a middle-of-the-road approach, which is reflected in presenting temporal sequences of still images, often has most pedagogical potential. Generally, it has been suggested that animations are useful if the corresponding learning task requires visualization of spatial, temporal or spatiotemporal changes (Rieber, 1991).

Taking into account that mental models in mechanics contain information about the spatial configuration of objects in the physical system and the information about objects' movement (Hegarty & Just, 1993), we hypothesized that simulations as well as temporal sequences of printed simulation frames could be fruitful for teaching one-dimensional kinematics.

The aim of our study was to investigate the impact of three different media types on learning performance in one-dimensional kinematics at middle years level. Specifically, the effectiveness of following media was compared:

1. simulations
2. printed sequences of characteristic simulation frames
3. isolated still diagrams as typically used in conventional instruction about one-dimensional kinematics

As far as we know, there are no other studies on relative efficacy of using these types of media for purposes of teaching and learning of one-dimensional kinematics.

REVIEW OF THE LITERATURE

Sources of students' difficulties in learning one-dimensional kinematics

According to Hestenes, Wells & Swackhammer (1992), one source of student difficulties with kinematical concepts is related to the fact that students' commonsense concept of motion is "vague and undifferentiated" (p.143). Thus, students find it difficult to differentiate between the concepts of speed and velocity (Pena & Alessi, 1999) as well as between the concepts of velocity and acceleration (Trowbridge & McDermott, 1981). This could be related to different meanings of the abovementioned concepts in everyday and scientific communication (Reif, 2010).

The way in which kinematics has been traditionally presented and taught further contributes to students' conceptual confusion. According to Arons (1997), in the physics teaching practice we often incline towards excessive didactic simplification which in the end mostly proves to be counterproductive. For example, in physics equations, the notions of instants and time intervals are often not consistently used. We could say that this also holds for the concepts of position and displacement, as well as for the consistent use of vectors.

Another source of student difficulties can be found in the high level of abstractness of kinematical concepts. Butterfield (as cited in Knight, 2004) considered the development of kinematical concepts as one of the greatest achievements of the human intellect. So it should not be overly surprising to realize that our students have difficulties in developing these concepts within a few teaching hours – the human kind failed to fully develop these concepts until seventeenth century. In that sense, it is especially difficult for the human mind to get along with the idea of instantaneous quantities and continuous change in motion (Arons, 1997; Sengupta & Farris, 2012).

Finally, according to Lichtenberger *et al* (2014), a necessary but not sufficient condition for successful learning of kinematics is reflected in the student's ability to correctly use the mathematical concept of rate and the ability to perform manipulations with vectors.

Reformed approaches to teaching and learning kinematics

It is widely accepted that for assimilation of abstract concepts they should be intensively used in concrete situations. According to Arons (1997), for learning kinematics it is very important to observe an object's motion, measure its positions at some instants of time and to calculate the changes of position and other kinematical quantities over time. In this way, students learn to associate the instantaneous values of physical quantities with concrete time instants, and they come to realize the difference between a time instant and a time interval.

Many of the desirable learning experiences as described above can be effectively created by the appropriate use of modern educational technologies, like MBL, digital video analysis and simulations. These technologies share a common pedagogical feature, which is reflected in the possibility of simultaneous displaying of object's motion and multiple representations of kinematical concepts describing that motion (e.g. real-time graphing). This helps students to establish cognitive links between the observed physical events and corresponding (events within) abstract representations (Beichner, 1996; Brassel, 1987). Additionally, the use of modern technologies often reduces the time necessary for data collection leaving more time for data analysis and discussions (Thornton & Sokoloff, 1990).

For purposes of our study, it is especially important to discuss the pedagogical potential of simulations and static diagrams.

Learning about one-dimensional kinematics from simulations and static diagrams

According to Banks, Carson, Nelson and Nicole "*simulation is the imitation of the operation of a real-world process or system over time*" (2010, p.3). Some pedagogical opportunities which can be associated with using computer simulations are as follows (Jimoyiannis & Komis, 2001; Christian & Belloni, 2001): setting and testing hypotheses, learning by observing multiple representations and translating among them, manipulating parameters, visualizing the change in phenomena related to the change of parameters and demonstrating complex virtual experiments or instruments.

Hegarty (2014) defines static diagrams as "*spatial representations, that is, visual-spatial arrays in which information is communicated by spatial properties such as shape, location, and adjacency of parts*" (p. 677). Thereby, in diagrams of physical systems spatial relations between objects of the representation are isomorphic to relations between the physical objects they represent. According to Rieber (1991), diagrams facilitate search and recognition processes when solving problems in content areas in which information is spatially organized.

Understanding dynamic events from static diagrams often depends on the student's ability of mental animation (Hegarty, Kriz & Cate, 2003). However, people do not spontaneously animate static diagrams, but it seems that mental animation can be facilitated by using series of static diagrams which represent the kinematics of a phenomenon (Hegarty, 2014; Mayer, Hegarty, Mayer & Campbell, 2005). In that sense, Knight (2004) emphasizes the usefulness of motion diagrams for teaching kinematics. Thereby, he thinks of motion diagrams as "*different frames in a movie of the object…or as an object lit by a flashing strobe light*" (p.76).

The main difference in learning kinematics from static diagrams in comparison to learning from animations is related to the fact that learning from animations requires the learner to perceive the spatiotemporal changes, whereas learning from diagrams depends on the ability to infer these changes (Hegarty, Kriz & Cate, 2003).

In the teaching practice, it is of essential importance to ensure an alignment between the learning goals and corresponding teaching/learning activities. However, it is equally important to carefully choose those educational technologies that will maximally facilitate the design of learning activities.

For this paper, it is important to note that all the previously mentioned learning experiences that are theoretically supposed to foster the understanding of kinematics can be effectively created by using Physlets® (Christian&Belloni, 2004). Physlets are small Java Applets which can be embedded in HTML documents and can interact with the user by employing Java Script (Titus, 1998). The Physlets which were developed for facilitating learning of kinematics typically contain dynamic visualizations of objects' motion, whereby in nearly all Physlets the user is also provided with the opportunity to measure the position of the object. Further, in most Physlets, by starting the animation one automatically switches on a stopwatch which can be used for measuring time, when needed. The object's motion is typically described by using multiple representations, whereby the user is often provided with the opportunity to observe real-time graphing. From the perspective of multimedia learning (see Clark & Mayer, 2011), one important feature of Physlets is that they allow the user to control the pace of the simulation and they do not contain superfluous graphics which lowers the probability of extraneous processing.

Physlets can be used for illustrating concepts and phenomena, as well as for formulating physics problems (Christian & Belloni, 2001). Physlet problems better resemble the main characteristics of the scientific inquiry in comparison to traditional textbook problems. They cannot be solved by using plug-and-chug approaches. The learner is required to conceptualize the problem and to decide which quantities should be measured - similarly to real world problems there is always an excess of information. The data taken from the simulation are then used for purposes of problem solving. In Fig. 1, we provide a screenshot which illustrates a 2-d kinematics Physlet problem, where learners are required to find the minimum velocity of the ball before it falls to the ground. Students are allowed to measure time and positions of the ball. Information regarding units is provided in the item stem.

Typically, there are multiple possible ways for solving a problem which potentially positively influences the development of students' creativity.

Finally, one very important distinguished feature of Physlets is related to the fact

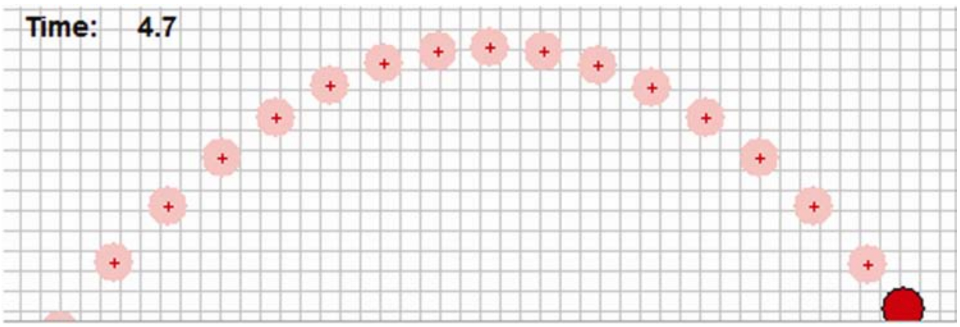

Figure 1. Screenshot of a 2-d kinematics Physlet-problem

that Physlets cover a very broad spectrum of topics that are typically taught in introductory physics courses (Christian & Belloni, 2004).

METHODS

Research questions

We wanted to answer to following research questions:

1. What is the relative impact of three different media types (simulations, printed sequences of simulation frames, conventional static diagrams) on middle years students' understanding of one-dimensional kinematics?
2. What are the middle years students' attitudes towards learning and teaching about one-dimensional kinematics by using different types of media?

Research hypotheses

Taking into account the psychological theories on multimedia learning, the nature of learning of kinematics as well as the results of the prior research, we have set the following research hypotheses:

1. The use of simulations as well as the use of printed simulation frames in teaching of one-dimensional kinematics will have a larger positive impact on students' understanding in comparison to the use of conventional static diagrams.
2. The use of printed simulation frames in teaching of one-dimensional kinematics will have a larger positive impact on students' understanding in comparison to the use of simulations.

Research design

For purposes of investigating the relative effectiveness of different media types, a pre-post quasi-experimental design with three comparison groups has been implemented.

Further, for purposes of measuring students' post-treatment attitudes on learning and teaching one-dimensional kinematics, we performed the survey research.

Participants

In our study, we included three classes of students (N=63) who were enrolled in the International Baccalaureate Middle Years Program (IBMYP) at a Sarajevo (Bosnia and Herzegovina) gymnasium. The IBMYP is a five-year programme designed for students aged 11-16 (Middle Years Programme, n.d.). All the students, who participated in our study, were enrolled in the fourth year of the IBMYP and were mostly 15 year-olds.

In our sample of students, there were 32 girls and 31 boys, whereby the gender distribution was approximately the same in all three groups. Taking into account the planned duration of the experimental treatment (6 teaching hours), as well as the need to minimize the disruption of the everyday school processes (e.g. schedule of classes), we decided to avoid random assignment of students to comparison groups. Consequently, the comparison groups were obtained by means of the convenience sampling technique and each class has been associated with exactly one level of the treatment variable (i.e. type of media). For purposes of statistical analyses related to answering of the first research question, we only included students who took the pretest, as well as the posttest. Thus, the simulation (S) class included n=17 students, while the series of simulation frames (SSF) and conventional static diagrams (CSD) classes included n=16 and n=19 students, respectively. The size of these subsamples is acceptable – Gall, Gall and Borg (2003) recommend a sample size of at least 15 per group for experimental research.

Our conclusions regarding students' attitudes towards learning kinematics with different media were based on survey answers of 49 participants (S class, n=17; SSF class, n=16; CSD class, n=16).

Students in all classes were taught by the same teacher (age=32). At the time of the study, the teacher had 8 years of working experience in teaching high-school physics.

Relevant characteristics of the curriculum

All the students who participated in our study learned about one-dimensional kinematics for the first time in the 8th grade of primary school. The primary school curriculum in the Federation of Bosnia and Herzegovina does not provide explicit suggestions about the number of teaching hours which should be devoted to one-dimensional kinematics, but typically teachers devote approximately 5 teaching hours to this topic. Thereby on average, students are as 13 year-olds introduced to the concepts of position, displacement, speed, velocity, acceleration, uniform rectilinear motion and uniformly accelerated motion. Traditionally, the primary school curricula in Bosnia and Herzegovina do not foster sufficiently students' development of graphing skills.

After the 9th grade of primary school, the students from our study were enrolled directly in the fourth year of the IBMYP, where they were supposed to learn about one-dimensional kinematics again.

The main textbook used in their physics classes is *Advanced Physics for You* by Johnson, Hewett, Holt & Miller (2000). Specifically, the students are supposed to learn at a deeper level about all the concepts and types of motion which they had earlier encountered during their primary education. One big difference between our students' IBMYP and primary school curriculum of one-dimensional kinematics is related to the much higher emphasis on creating and interpreting graphs within the IBMYP curriculum. For example, students are expected to learn more about the physical meaning of gradients at points on a given curve, as well as about the meaning of areas under graph curves. Furthermore, the vector nature of kinematical concepts is more emphasized. In our study, altogether 6 teaching hours were devoted to the teaching unit "one-dimensional kinematics" (see Table 1).

Manipulation of the treatment variable

The quasi-experiment has been conducted as a part of regular teaching activities within the context of the teaching unit "one-dimensional kinematics". In all three classes, the same learning goals were set and the same concepts were introduced.

Table 1. Number of teaching hours devoted to research/teaching activities

Number of teaching hours	Activity
1	Pretest – Week 5 (after start of the school year)
2	Introduction to kinematics; Uniform motion (Development and application of concepts) – Week 6
2	Uniformly accelerated motion (Development and application of concepts) – Week 7
2	Application and transfer of learned concepts – Week 8
1	Posttest – Week 9
1/2	Survey of student attitudes – Week 10 (after start of the school year)

Further, a similar teaching pattern has been used in all groups. Firstly, the teacher verbally presented basic facts regarding the concept which she wanted to introduce. This verbal presentation was typically very short and it was immediately followed by visualization and application activities. For purposes of visualization and application activities in different classes, different media have been used. Specifically, the following media have been used: simulations (class S), sequences of printed simulation frames (class SSF) and conventional static diagrams (class CSD).

Unfortunately, because of technical limitations, not all students in class S could directly interact with the simulations. Instead, the teacher ran the simulations and moderated the classroom discussion about the phenomena and representations displayed in the animation. In order to make a minds-on environment more probable, the teacher applied the predict-observe-explain technique whenever it was possible. Further, the teacher prepared worksheets for each of the visualization and application activities. In these worksheets, there were tables which were supposed to be filled out by the students. In order to fill out the tables, it was necessary to measure physical quantities and (in certain circumstances) to perform calculations in order to determine the values of some other quantities. As noted earlier, the measurements were taken by the teacher who guided the students through all these activities via classroom discussion. For example, the teacher discussed with students about the contents of the simulation and in certain circumstances she also asked them which measurements should be taken.

In the SSF class exactly the same visualization and application activities were implemented as in the class S. The only difference was that, instead of watching simulations, SSF students got sequences of characteristic simulation frames in their worksheets, in addition to tables. Thereby, they could take data from these sequences of frames on their own. At the start, they were provided with information regarding the scale (e.g. length of the edge of a square in the frame grid), and (if necessary) with information about the origin of the coordinate system. The didactic potential of this type of media influenced a different role of the teacher in this group, as compared to her role in the S class. In the SSF group, the teacher presented the activities to her students, monitored their work and engaged in clarification activities, when needed. Students spontaneously engaged in discussions amongst themselves.

In the CSD class the same concepts were introduced as in the other two groups and the students were trained to acquire the same scientific skills. Furthermore, the sequence with which concepts were introduced was also the same. However, the visualization and application activities were accompanied by the use of conventional static diagrams which can be typically found in standard textbooks. After short verbal presentation regarding a concept, the teacher typically asked the students to apply the concept, whereby they had to engage in cognitive processing of static diagrams (mostly drawn on the chalkboard). These questions were followed by corresponding classroom discussions.

During application lessons students in class S and SSF solved Physlet-problems presented in simulations and sequences of simulation frames, respectively. On the other side, students from the CSD class solved typical textbook problems (mainly from: Johnson *et al*, 2000). In all three groups, a similar teaching pattern has been used. After a problem has been formulated, one of the students was required to solve it on the chalkboard, whereby she/he has been monitored and guided by the teacher. The other students filled out the prepared worksheets (class S and SSF), or solved the problems in their pads (CSD).

For purposes of further illustration of the three teaching approaches, below is the description of two activities conducted during the development and application lessons. Our first example is related to the exploration of the meaning of slopes in position *vs.* time graphs.

In the S class, the teacher discussed with students the Physlet-Illustration 2.1 (Christian & Belloni, 2004) whose simulation frames are showed in Fig. 2. The students in SSF class were given these simulation frames on their worksheets. Students from both groups were required to fill out the corresponding fields in their worksheets, in order to calculate the velocities of the trucks. SSF class students took the relevant measurements from the simulation frames, whereby the measurement process in the S class was guided by the teacher.

Finally, in the CSD class, the teacher drew the same position *vs.* time graphs on the chalkboard as were shown in the other two groups (i.e. she drew one of the frames), whereby she discussed the procedure of inferring information about velocity from the slope of the position *vs.* time graph with students. The main difference between activities in this group and the previous two groups is related to the fact that CSD students did not have the opportunity to observe the motion of the objects which correspond to the displayed graphs. On the other side, the simulation provided the option of real-time graphing, and students could observe how increasing of x-separations between the trucks, is associated with increase of y-distances between the corresponding line graphs. This kind of experience could potentially prevent the development of "graph as picture of motion" misconceptions (see Beichner, 1994).

Our second example is related to an application lesson activity which was supposed to reinforce learning of the concepts of uniform and uniformly accelerated

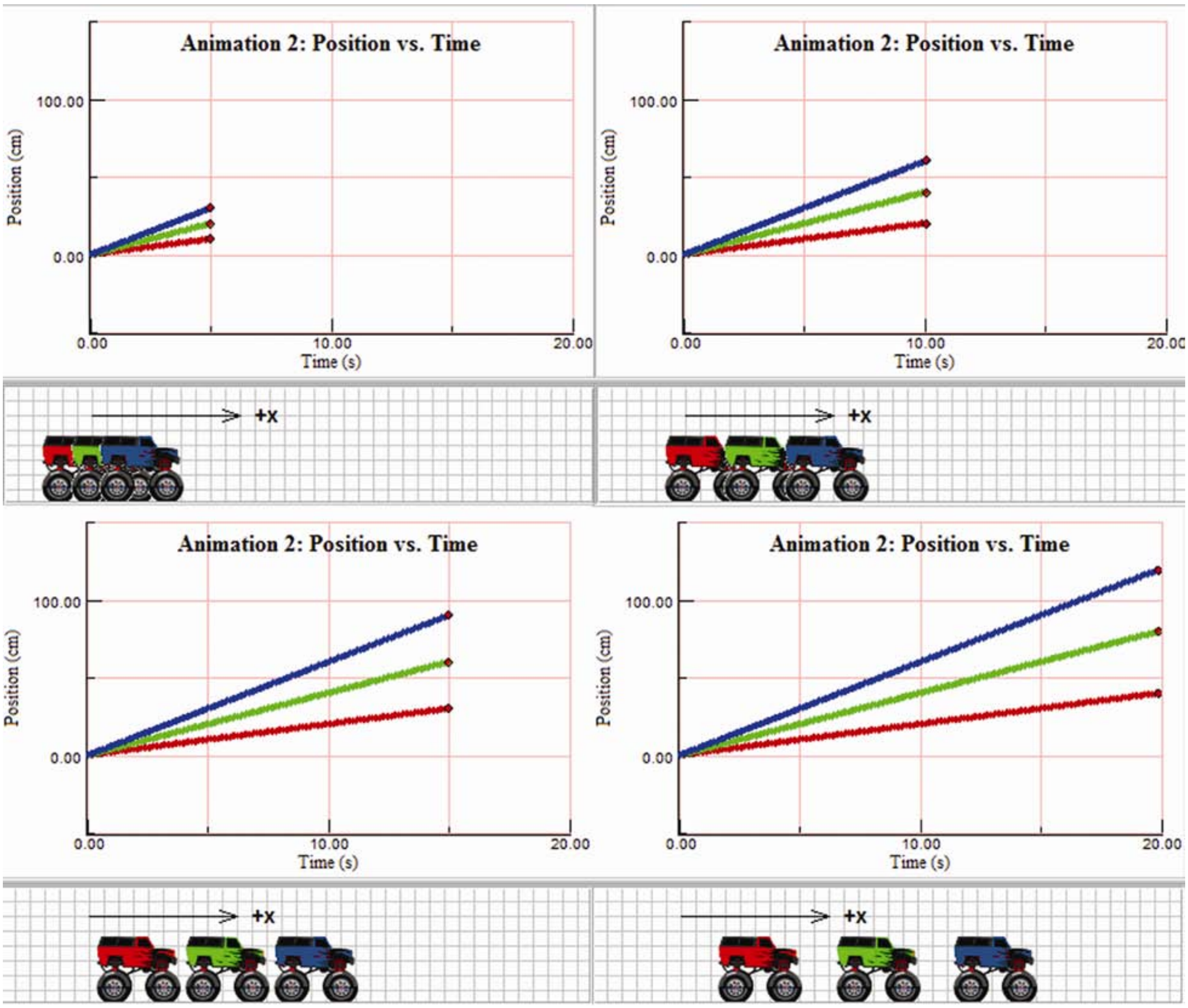

Figure 2. Simulation frames from Physlet-Illustration 2.1 (Christian & Belloni, 2004)

motion, as well as to strengthen students' graphing skills. Students from class S and SSF were given the Physlet-problem 2.8 (Christian & Belloni, 2004):

The purple truck is catching up to the yellow truck (position is given in meters and time is given in seconds).

a. *If the trucks continue, at what clock reading, t, will the purple truck pass the yellow truck?*
b. *At what position, x, does the purple truck pass the yellow truck?*
c. *On one graph, plot x vs. t for each truck. Verify your answers for parts (a) and (b).*

Thereby, students from the SSF class got worksheets with simulation frames from Fig. 3, and students from the S class were presented the corresponding simulation (it has been used in similar pedagogical way, as described earlier).

In the CSD group, the textual part of the problem statement has been approximately the same, and they were additionally given the initial values for position and velocity of both trucks, as well as information about the type of motion of the trucks and acceleration of the purple truck. In the early phase of the problem solving process the teacher discussed with students how to picture the problem, which resulted with providing corresponding static diagram on the chalkboard.

In our opinion, the Physlet-based problem better reflects the process of scientific inquiry. As a matter of fact, the students in S and SSF classes were not provided with the information about the type of object's motion – they had to analyze tabular data in order to realize that the yellow truck performs uniform motion and purple truck performs uniformly accelerated motion. This type of problems cannot be solved by using a "plug-and-chug approach".

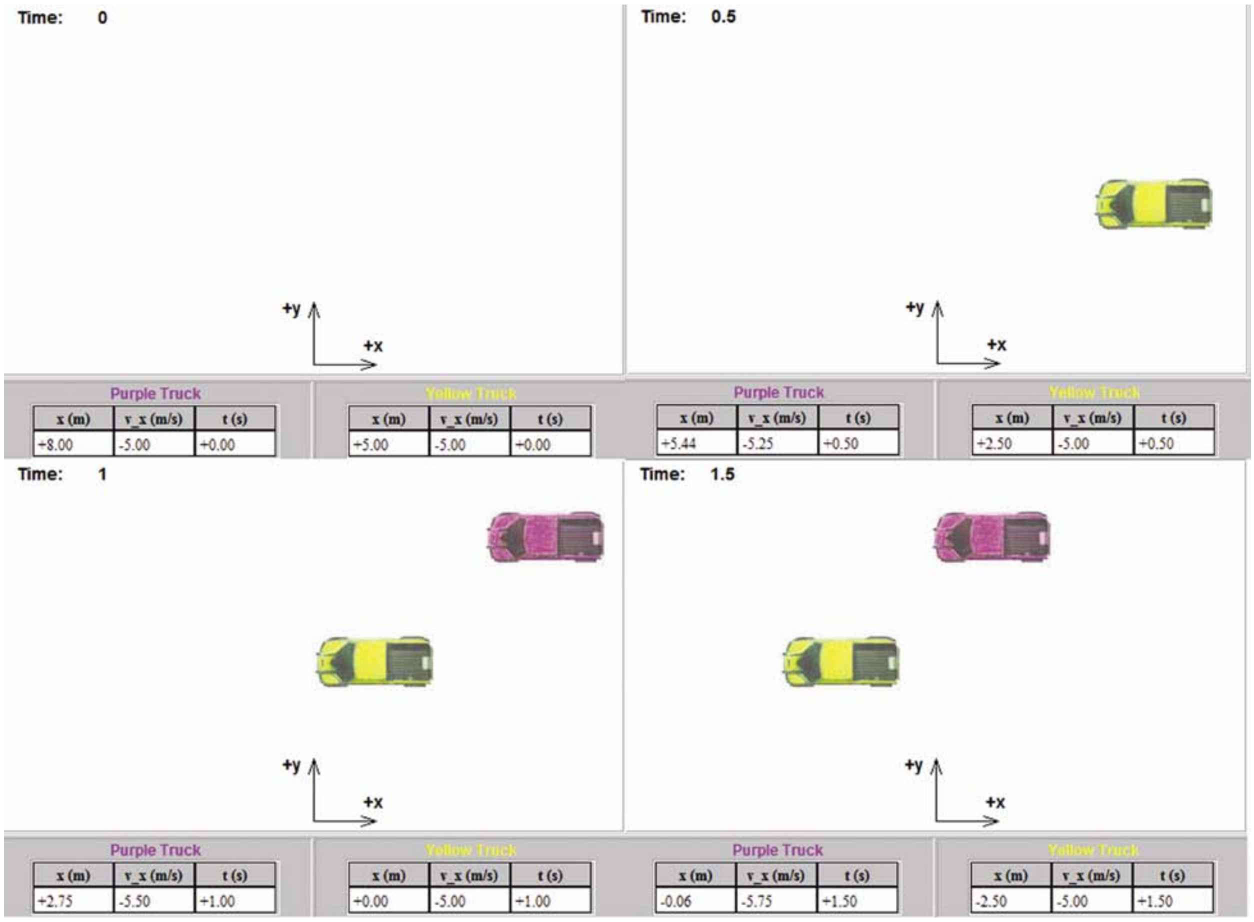

Figure 3. Simulation frames from Physlet-problem 2.8 (Christian & Belloni, 2004)

Generally, the following Physlets from the book by Christian & Belloni (2004) have been used in our study: Physlet-illustrations 2.1 through 2.5, Physlet-explorations 2.1 through 2.8 (with exception of 2.6), Physlet-problems 2.1 through 2.5, 2.8, 2.11, 2.13 and 2.16.

Measurement of the constructs

In order to answer our first research question, we had to create a test that measures students' understanding of one-dimensional kinematics. According to Ford (2011) "conceptual understanding is that which permits one to transfer the explanation of a phenomenon to different variations of a situation that have been already analyzed, and can be proof of the ability of any learner to grasp the concepts of scientific phenomena" (p. 18). It is important to note that in case of one-dimensional kinematics, conceptual understanding is closely related to the ability of translation between multiple representations of kinematical phenomena. In their test instrument which was supposed to measure conceptual knowledge of one-dimensional kinematics, Lichtenberger et al (2014) included items with images (e.g. stroboscopic pictures), items with tables of values and items with graphs. In addition to these representations, we decided also to include items which required only the use of verbal representation. Altogether, our test instrument consisted of 15 multiple-choice (MC) items, each item containing one right answer and four distracters. The frequency of different representations, as well as the source of individual items is specified in Table 2.

The concepts which were covered are as follows: position, distance, displacement, speed, velocity, acceleration, uniform motion, accelerated motion and uniformly accelerated motion. Ten out of 15 MC items were taken from four earlier validated instruments that are widely used within the physics education research community – **F**orce **C**oncept **I**nventory (Hestenes, Wells, & Swackhammer, 1992), **M**echanics **B**aseline **T**est (Hestenes & Wells, 1992), **T**est of **U**nderstanding **G**raphs in **K**inematics (Beichner, 1994) and **F**orce and **M**otion **C**onceptual **E**valuation (Thornton & Sokoloff, 1998). Five items were specially created for the purpose of this study (items 8 through 12). In item 8, students were supposed to differentiate between the concepts of distance and displacement, i.e. to recognize that for a body which returns to its starting position the displacement is zero. In order to solve the item 9 students had to think of the vector nature of acceleration. Specifically, they had to realize that the acceleration vector of a vertically thrown ball did not change until the ball fell to the ground. In items 10 through 12, students were expected to interpret tabular representations of position or velocity over time, in order to draw conclusions about the type of the motion of the object or about the velocity and acceleration vectors during some given time intervals.

Taking into account that most questions originated from validated (force and motion) instruments, as well as the fact that all the included concepts were covered in the one-dimensional kinematics teaching unit, we can say that there is solid evidence that valid conclusions can be inferred from the test scores. When it comes to the reliability of test scores, the KR-20 of the pretest amounted to 0.55 and on the

Table 2. Distribution of content representations across the test items; In parentheses, the ordinal number of the item in the original test is provided

Item 1	**Item 2**	**Item 3**	**Item 4**	**Item 5**	**Item 6**	**Item 7**	**Item 8**
Stroboscope	Stroboscope	Stroboscope and graphs	Stroboscope and graphs	Graphs	Graphs	Graphs	Verbal
FCI (19.)	FCI (20.)	MBT (1.)	MBT (2.)	TUG-K (4.)	TUG-K (6.)	TUG-K (8.)	New
Item 9	**Item 10**	**Item 11**	**Item 12**	**Item 13**	**Item 14**	**Item 15**	
Verbal	Tabular	Tabular	Tabular	Graphs	Graphs	Graphs	
New	New	New	New	TUG-K (3.)	TUG-K (20.)	FMCE (slightly modified 25.)	

posttest KR-20 amounted to 0.65. These values are surely not impressive. However, there is no agreement over the minimum acceptable standards of scale reliability – some researchers regard 0.7 as a minimum, whereas others take 0.5 as still acceptable (see Bowling, 2005, p. 397). Generally, the size of the reliability measure influences how much the observed effect size can get close to the true size of the effect – higher reliabilities make it more probable to observe larger effect sizes (Furr & Bacharach, 2013).

The average item difficulty index amounted to 0.26 and 0.52 in pretest and posttest, respectively. Average item difficulty index of 0.5 is considered to be optimal (Cohen & Swerdlik, 2009). Finally, the average discrimination coefficient (as measured by the point biserial coefficient) amounted to 0.36 and 0.41 in pretest and posttest, respectively. Item discrimination indices above 0.3 can be considered as satisfying (Fisseni, 1997).

Besides administering the main test instrument whose aim was to measure students' understanding of one-dimensional kinematics, we also asked the students to solve two constructed-response problems. The first of these problems was created to intentionally favor the S and SSF groups (it required taking measurements from the coordinate grid); whereas the second one was supposed to favor the CSD group (it was similar to typical textbook problems). The primary aim of giving these constructed response problems to our students was to get a first sense about the flexibility of their knowledge (e.g. to test students' ability to transfer knowledge to relatively "distant" contexts) as well as about the creativity of their approaches to problem solving. Precise problem statements are given in Appendix A.

In order to obtain interval measures which reflect student attitudes towards learning and teaching of one-dimensional kinematics, we approached the problem of survey data analysis from a Rasch modeling perspective (see Boone, Staver & Yale, 2014).

Our survey instrument included five Likert-items (with five answering choices) which measured students' post-treatment attitudes on learning and teaching of one-dimensional kinematics (person reliability=0.64) as well as three items that specifically probed students' opinions on physics problem solving (person reliability=0.1). Because of the very low reliability of person measure estimates on the "attitudes towards problem solving scale", we decided to give up our initial aim of discussing students' post-treatment differences in attitudes towards physics problem solving. For the five remaining items, the Outfit MNSQ fit statistics were as follows: 0.68 (item 1), 1.01 (item 2), 0.97 (item 3), 0.73 (item 4) and 1.55 (item 8). It follows that items 1 through 4 fit very well the Rasch model, whereby the item 8 is not productive for constructing a measurement system, but it is also not degrading it (see Wright & Linacre, 1994).

Further, in our survey, students were also supposed to express, in their own words, their general impression on the way one-dimensional kinematics had been taught to them. Finally, students from S and SSF groups were asked whether they would like to learn with Physlets/series of simulation frames in the context of other teaching units. The complete survey can be found in Appendix B.

RESULTS

What is the relative impact of three different media types on students' understanding of one-dimensional kinematics?

In order to answer our first research question, we analyzed students' pretest and posttest scores, as well as their normalized individual gains (see Smith, Wittmann & Carter, 2014). The results of the descriptive analyses are given in Table 3.

Table 3. Mean values and standard deviations (in parentheses) of pretest scores, posttest scores and normalized individual gains

	Simulations (S class)	Series of simulation frames (SSF)	Static diagrams (CSD)
Pretest	3.70 (3.04)	3.12 (1.26)	4.74 (2.13)
Posttest	8.29 (2.49)	8.69 (3.22)	6.47 (2.67)
Normalized gains	0.38 (0.25)	0.45 (0.31)	0.13 (0.31)

Note: The maximum of the test score scale is 15

Table 4. Average within-group gender differences (score for girls – score for boys) on: pretest, posttest, normalized individual gains

	Simulations (S class)	Series of simulation frames (SSF)	Static diagrams (CSD)
Pretest difference	-3.86 (1.15)	-1.25 (0.56)	-2.45 (0.81)
Posttest difference	-0.62 (1.24)	3.62 (1.36)	-1.32 (1.22)
Normalized gains difference	0.17 (0.12)	0.38 (0.12)	0.09 (0.14)

Note: Standard errors of the differences are given in parentheses. Maximum of the test scale is 15.

The next step was to test for statistical significance of between-group posttest differences, while controlling for corresponding pretest differences. To that end, we decided to conduct a one-way analysis of covariance (ANCOVA) on our data. However, in order to be as confident as possible in the results of ANCOVA, we had to test its assumptions before going on with the interpretation of the ANCOVA results. First, we checked the assumption of "independence of covariate and treatment". As a matter of fact, by conducting a one-way ANOVA we could show that the between-group differences on the pretest were not statistically significant, F (2,49)=2.28, p>0.05. Thus, one assumption for conducting an ANCOVA with group as treatment variable, and pretest score as covariate has been fulfilled.

Besides being in accord with the "independence of covariate and treatment" assumption, our data also met other important assumptions of ANCOVA, such as the assumptions of: homogeneity of variances, homogeneity of regression slopes, normal distribution of errors and independence of errors.

The results of ANCOVA show that there is a significant effect of media types on students' understanding of one-dimensional kinematics after controlling for the effect of pretest-differences, F (2,48)=4.27, p<0.05, partial η^2 (eta squared)=0.15.

Contrasts revealed that teaching with series of simulation frames significantly increases students' understanding of one-dimensional kinematics compared to conventional teaching with static diagrams, $t(48) = 2.73$, $p < 0.05$, $r = 0.37$, but not compared to teaching with simulations, $t(48)=0.58$, $p>0.05$, $r = 0.08$. The difference in adjusted posttest means between SSF and CSD amounted to 2.66, which corresponds to a difference of 17.8% (i.e. 59.4%-41.6%).

Similarly, it has been shown that teaching with simulations is significantly more effective for developing students' understanding of kinematics in comparison to conventional teaching with static diagrams, t(48)= 2.25, p <0.05, r = 0.31. The difference in adjusted posttest means between S and CSD amounted to 2.11, which corresponds to a difference of 14.1% (i.e. 55.7%-41.6%)

We decided also to investigate the gender differences on the dependent variable (understanding of one-dimensional kinematics) and to relate these differences to the use of different types of media. For that purpose, we separately analyzed gender differences in each of the three classes (Table 4).

We checked the distributions of the gain (ordinary gain=posttest score – pretest score) scores across the groups, whereby we noticed that these distributions did not significantly deviate from normality. So we decided to use a t-test in order to find out whether the difference in gain scores between boys and girls was statistically significant. The results of the t-tests showed that the girls' ordinary gain scores were statistically significant higher than boys' gain scores in the S (t(15)= 2.26, p<0.05, r=0.5) and SSF classes (t(14)= 3.53, p<0.05, r=0.69), but not in the CSD class (t(17)= 0.95, p>0.05, r=0.22). However, the significance of the gender-gain relationship in the S class vanished when we investigated gender differences on the normalized gain measure, rather than using the ordinary gain measure. In that case, only in the SSF group the normalized gain for girls was statistically significantly higher than the normalized gain for boys (U=5.5, z=2.80, p<0.05, r=0.7), whereas in the other two classes the relationships between gender and normalized gain proved to be non-significant. Here, the Mann-Whitney's U statistics was used instead of the t-test, because the distribution of girls' normalized gain scores in the SSF class was skewed and non-normal.

As earlier stated, besides 15 MC items we gave our students also two constructed response items, which were supposed to give us a first sense about the flexibility of students' knowledge (Item 1), as well as about the creativity of their approaches to solving quantitative exercises (Item 2).When it comes to students' achievement on the two constructed response items, it should be noted that on the pretest the overall rate of students' success on the Item 1 was 0%, whereas the Item 2 has been solved by only two (out of 17) students from the S class. The post-test results for the two constructed response items are given in Table 5.

What are the students' attitudes towards learning and teaching about one dimensional kinematics by using different types of media?

By means of Rasch analysis, we could estimate for each person from our sample an interval measure which reflects the degree of their positive attitudes towards learning and teaching about one dimensional kinematics. Then, we used ANOVA for purposes of exploring the between-group differences. The ANOVA shows that there are statistically significant between-group differences in attitudes, F (2, 46)=4.30, p<0.05, η^2=0.16. Specifically, the attitudes of students from S (t (46)=2.26, p<0.05, r=0.32) and SSF classes (t(46)=2.75, p<0.05, r=0.38) were significantly more positive than attitudes of students from the CSD class. The difference between the S and SSF classes was not statistically significant, t(46)=0.53, p>0.05.

Our survey also contained a question in which students were expected to write about their general impression regarding their experience of learning about one-dimensional kinematics. Students' answers were categorized into three categories: positive, neutral, and negative impressions. The results of the analysis of student answers are given in Table 6.

Finally, in Table 7 we present information about students' attitudes towards an eventual use of the S and SSF teaching/learning approach in other teaching areas of physics.

Table 5. Proportion of correct answers (posttest) on constructed response items

	S class	SSF class	CSD class
Item 1	0.35 (0.12)	0.56 (0.12)	0.05 (0.05)
Item 2	0.18 (0.09)	0.06 (0.06)	0

Note: Standard errors are in parentheses.

Table 6. Proportions of students who exhibited positive, neutral or negative impressions about their learning experience within the teaching unit "one-dimensional kinematics"

	Negative impression	Neutral impression	Positive impression
S class	0	0.06 (0.06)	0.94 (0.06)
SSF class	0.06 (0.06)	0.19 (0.10)	0.75 (0.11)
CSD class	0.31 (0.13)	0.23 (0.12)	0.46 (0.14)

Note: Standard errors are in parentheses.

Table 7. Degree of agreement with the statement: “I think that Physlets/sequences of simulation frames should be also used in other physics teaching units”

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
S class	0	0	0.12 (0.08)	0.23 (0.10)	0.65 (0.12)
SSF class	0.13 (0.09)	0	0.33 (0.12)	0.33 (0.12)	0.20 (0.10)

Note: The numbers in the cells represent proportions of students who selected a particular option from the Likert scale. Standard errors are in parentheses.

As we can see from Table 7, a large majority of students from the S and SSF classes expressed their willingness to continue learning with simulations/sequences of simulation frames. The results from Table 7 further support the thesis that students perceived the S and SSF learning approaches as effective and/or interesting. This perception was particularly pronounced in students who learned from simulations.

DISCUSSION

Our first research question required us to investigate the relative impact of simulations, sequences of simulation frames and conventional static diagrams on students’ understanding of one-dimensional kinematics. By means of ANCOVA, it has been shown that students from the S and SSF classes significantly outperformed their peers from the CSD class, whereby medium effect sizes have been observed. The largest effect size has been found for the SSF class – the adjusted percentage of correct answers on the post-test was approximately 18% higher for students from the SSF class than for students from the CSD class. In our opinion, the best theoretical explanation for the better achievement of students from the S and SSF classes is related to the fact that they were provided with more stimulating learning environments in comparison to the students from the CSD class. Specifically, the pedagogical potentials of the chosen simulations and sequences of simulation frames made it possible to create learning environments in which students were provided with the opportunity to acquire the experiences that are theoretically supposed to foster understanding of kinematics. As earlier stated, it is emphasized in the relevant literature that observing motion, taking measurements and observing real-time graphing are experiences that facilitate learning of kinematics (Arons, 1997; Knight, 2004). The teachers can create these experiences by using different types of tools, i.e. different types of media. However, it is easier for the teacher and less time-consuming to create the desirable learning experiences with some tools than with others. The results of our study suggest that simulations and sequences of simulation frames can be powerful tools for teaching of kinematics. This conclusion is consistent with the results of some earlier studies (Pena&Alessi, 1999; Jimoyiannis & Komis, 2001; Ploetzner, Lippitsch, Galmbacher, Heuer & Scherrer, 2009; Mayer et al, 2005). Specifically, in the study by Mayer *et al* (2005), it has been found that in 4 of 8 comparisons there were no significant differences between learning from animations and sequences of animation frames, whereas in 4 comparisons learning from sequences of animation frames proved to be more effective. It seems that learning from sequences of simulation frames shares some positive features of both – learning from dynamic and learning from static media. Specifically, the learners are required to actively engage in processes of mental animation in order to infer object’s motion. However, mental animation is facilitated in comparison to the case of conventional static diagrams, because a (temporal) sequence of images is provided. Additionally, the type of the media that was used in the SSF class had more potential to facilitate self-paced learning in comparison to the media selected in the other two groups. The effects of self-paced learning could be further investigated in some future studies by allowing the students from the S class to interact with simulations on their own. As earlier stated, in our study this was not possible, because of technical limitations related to the number of computers that the teacher had at her disposal.

When it comes to treatment-gender interactions, our results suggest that the facilitating of mental animation has a particularly positive influence on girls' learning of one-dimensional kinematics. This conclusion seems to be consistent with results from some earlier studies in which it has been found that boys outperform girls on most measures of visuospatial abilities (Halpern *et al*, 2007). As a matter of fact, in the study by Sanchez & Wiley (2010) it has been found that simulations possess the potential of closing the gender gap in science. Generally, the positive effect of using simulations or sequences of simulation frames on girls' achievement in science could be explained by the theory of internal-external representational coupling (see Nersessian, 2008). Specifically, information is processed in a coupled system of internal and external representations. Thus, the presentation of adequate external representations could be related to reducing the cognitive load associated with internal visualization processes.

When it comes to students' achievement on the two constructed response items (see Appendix A), we should note that in the post-test condition there was a considerable proportion of students from S and SSF classes who were able to transfer their knowledge from the context of one-dimensional kinematics to the context of two-dimensional kinematics. However, the proportion of correct answers on the second item (which required the students to solve a quantitative exercise) was surprisingly low across all three groups of students. In the stem of the second item, we intentionally provided more information than it is necessary for item solving, in order to check whether students from different groups will approach the problem in different manners (i.e. going to the solution in a harder or easier way). We can only hypothesize that the excessive information confused the students. An alternative explanation would be that none of the used teaching approaches sufficiently developed students' competences in solving (typical) quantitative problems. Further research, with a larger number of constructed response items, is needed to give a valid explanation of these findings.

Our survey research revealed that the post-treatment attitudes towards the learning and teaching of one-dimensional kinematics were significantly more positive for students from S and SSF classes, in comparison to their peers from the CSD class. The observed effects were of medium size. Again, the largest positive effect was associated with learning from simulation frames. However, students' general impression on their learning experiences was most positive in the S class – 94% of students reported positive impressions. The proportion of students who reported positive impressions for the SSF approach was also very high, but somewhat lower than in the S class. Specifically, while many students from S and SSF classes were reporting that "*kinematics is interesting and easy to grasp*" some students from the CSD class were reporting that "*kinematics is boring*", as well as "*hard to grasp*". In our opinion, the result according to which the majority of S and SSF students would also like to learn other teaching units by using simulations/sequences of frames additionally reinforces the validity of our earlier conclusions related to the results of the attitude survey. These findings are in line with some earlier research. As a matter of fact, in the relevant literature it is emphasized that computer simulations have great potential to spark students' interest and motivate them for learning (National Research Council, 2011). Further, Wieman, Adams & Perkins (2008) point out that in one of their studies students had "*expressed a strong preference of simulations over the real equipment*" (p. 683).

CONCLUSIONS

In our study, we investigated the impact of different media types on students' learning of one-dimensional kinematics, as well as students' post-treatment attitudes towards this teaching unit.

Our conclusions are as follows:

- When it comes to the teaching unit "one-dimensional kinematics", we can say that simulations and printed sequences of simulation frames have significantly greater potential for creating stimulating learning environments in comparison to conventional static diagrams. The largest impact on students' understanding of kinematics has been found for students who learned kinematics from printed sequences of simulation frames.
- The use of printed sequences of simulation frames seems to be a promising approach to closing the gender gap in teaching about one-dimensional kinematics.
- The students' attitudes towards learning about one-dimensional kinematics from simulations and sequences of simulations frames are very positive. Particularly positive general impressions about the teaching unit "one dimensional kinematics" were reported from students who learned from simulations.

Finally, it is useful to provide some notes of caution regarding the conclusions listed above:

- In general, it is true that simulations have greater potential for teaching kinematics in comparison to static images, but not all simulations are equally effective in all situations. When teaching kinematics, we should choose simulations which allow us to:

1. observe motion together with multiple representations of kinematical concepts which describe that motion
2. take measurements from the simulation and control pace of the simulation
3. change the physical parameters and observe the effects of these changes

- Further research is required in order to investigate whether a statistically significant difference between S and SSF classes would occur if all students from the S class were in the position to control on their own their learning with the simulations. As a matter of fact, Beichner (1990) points out that "immediate student control of the physical event and its graphical representation might be what makes MBL effective" (p. 803).
- The conclusion which relates the effectiveness of media types to gender is based on small sample sizes. It would be useful to conduct further experimental research in order to try replicating our finding.

In line with the abovementioned conclusions, our future research will be primarily directed towards studying the factor of students' control on effectiveness of simulations in teaching of one-dimensional kinematics, as well as to further investigation of the gender-treatment effect.

ACKNOWLEDGMENTS

The authors would like to thank Mrs. Aida Kalaba for careful reading and copyediting of the manuscript.

REFERENCES

Aguirre, J.M. (1988). Student preconceptions about vector kinematics. *The Physics Teacher, 26*, 212-216. doi: 10.1119/1.2342490

Arons, A.B. (1997). *Teaching Introductory Physics*. New York: John Wiley & Sons.

Banks, J., Carson, J.S., Nelson, B.L., & Nicole, D.M. (2010). *Discrete-Event System Simulation*. Upper Saddle River, NJ: Prentice Hall.

Beichner, R. (1990). The Effect of Simultaneous Motion Presentation and Graph Generation in a Kinematics Lab. *Journal of Research in Science Teaching, 27*, 803-815. doi: 10.1002/tea.3660270809

Beichner, R.J. (1994). Testing Student Interpretation of Kinematics Graphs. *American Journal of Physics, 62*, 750-762. doi: 10.1119/1.17449

Beichner, R.J. (1996). The impact of video motion analysis on kinematics graph interpretation skills. *American Journal of Physics, 64*, 1272-1277. doi: 10.1119/1.18390.

Boone, W.J., Staver, J.R., & Yale, M.S. (2014). *Rasch Analysis in the Human Sciences*. Dordrecht: Springer.

Bowling, A. (2005). Techniques of questionnaire design. In A. Bowling & S. Ebrahim (Eds.), *Handbook of health research methods: Investigation, measurement and analysis* (pp. 394-428). Maidenhead: Open University Press.

Brassel, H. (1987). The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. *Journal of Research in Science Teaching, 24*, 385-395. doi: 10.1002/tea.3660240409

Carson, R. & Rowlands, S. (2005). Mechanics as the Logical Point of Entry for the Enculturation into Scientific Thinking. *Science & Education, 14*, 473-492. doi: 10.1007/s11191-004-1791-9

Christian, W., & Belloni, M. (2001). *Physlets: Teaching Physics with Interactive Curricular Material*. Upper Saddle River, NJ: Prentice Hall.

Christian, W., & Belloni, M. (2004). *Physlet Physics: Interactive Illustrations, Explorations and Problems for Introductory Physics*. Upper Saddle River, NJ: Pearson Education.

Clark, R.C., & Mayer, R.E. (2011). *e-learning and the science of instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning*. San Francisco, CA: Pfeiffer.

Cohen, R.J., Swerdlik, M. (2009). *Psychological Assessment: An Introduction to Tests and Measurements*. Boston, MA: McGraw-Hill Higher Education.

Erceg, N., & Aviani, I. (2014). Students' understanding of velocity-time graphs and the sources of conceptual difficulties. *Croatian Journal of Education, 16*, 43-80.

Fisseni, H-J. (1997). *Lehrbuch der psychologischen Diagnostik* [Textbook of psychological diagnostics]. Göttingen: Hogrefe-Verlag.

Ford, K. (2011). *Inquiry Learning: Students' perception of light wave phenomena in an informal environment* (Unpublished doctoral dissertation). Southern University and A&M College, Baton Rouge.

Furr, R.M., & Bacharach, V.R. (2013). *Psychometrics: An Introduction* (2nd ed.). Thousand Oaks: SAGE.

Galili, I. (1995). Mechanics background influences students' conceptions in electromagnetism. *International Journal of Science Education, 17*, 371-387. doi: 10.1080/0950069950170308

Gall, M.D., Gall, J.P., & Borg, W.R. (2003). *Educational Research: An Introduction* (7th ed). Boston: Pearson Education.

Halloun, I. A., & Hestenes, D. (1985). Common sense concepts about motion. *American Journal of Physics, 53*, 1056-1065. doi: 10.1119/1.14031

Halpern, D.F., Benbow, C.P., Geary, D.C., Gur, R.C., Hyde, J.S., Gernsbacher, M.A. (2007). The Science of Sex Differences in Science and Mathematics. *Psychological Science in Public Interest, 8*, 1-51. doi: 10.1111/j.1529-1006.2007.00032.x

Hegarty, M. & Just, M.A. (1993). Constructing Mental Models of Machines from Text and Diagrams. *Journal of Memory and Language, 32*, 717-742. doi: 10.1006/jmla.1993.1036

Hegarty, M. (2014). Multimedia Learning and the development of mental models. In R.E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (pp. 673-701). Cambridge: Cambridge University Press.

Hegarty, M., Kriz, S., & Cate, C. (2003). The Roles of Mental Animations and External Animations in Understanding Mechanical Systems. *Cognition and Instruction, 21*, 325-360. doi: 10.1207/s1532690xci2104_1
Hestenes, D., & Wells, M. (1992). A Mechanics Baseline Test. *The Physics Teacher, 30*, 159-166. doi: 10.1119/1.2343498
Hestenes, D., Wells, M., & Swackhammer, G. (1992). Force Concept Inventory. *The Physics Teacher, 30*, 141-158. doi: 10.1119/1.2343497
Jimoyiannis, A. & Komis, V. (2001). Computer simulations in physics teaching and learning: a case study on students' understanding of trajectory motion. *Computers & Education, 36*, 183-204. doi: 10.1016/S0360-1315(00)00059-2
Johnson, K., Hewett, S., Holt, S., & Miller, J. (2000). *Advanced Physics for You*. Cheltenham: Nelson Thornes.
Knight, R. D. (2004). *Five Easy Lessons: Strategies for Successful Physics Teaching*. San Francisco, CA: Addison Wesley.
Lichtenberger, A., Vaterlaus, A., & Wagner, C. (2014). Analysis of student concept knowledge in kinematics. In C. P. Constantinou, N. Papadouris & A. Hadjigeorgiou (Eds.), *E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning. Part 11*(R. Millar & J. Dolin), (pp. 38-50) Nicosia, Cyprus: ESERA.
Mayer, R.E., Hegarty, M., Mayer, S., & Campbell, J. (2005). When Static Media Promote Active Learning: Annotated Illustrations Versus Narrated Animations in Multimedia Instruction. *Journal of Experimental Psychology: Applied, 11*, 256-265. doi: 10.1037/1076-898X.11.4.256
McDermott, L.C., Rosenquist, M.L., & van Zee, E.H. (1987). Student difficulties in connecting graphs and physics: examples from kinematics. *American Journal of Physics, 55*, 503-513. doi: 10.1119/1.15104
Middle Years Programme (n.d.). Retrieved December 16, 2014, from http://www.ibo.org/en/programmes/middle-years-programme
National Research Council. (2011). *Learning Science through Computer Games and Simulations*. Washington: National Academies Press.
Nersessian, N.J. (2008). *Creating Scientific Concepts*. Cambridge: The MIT Press.
Pena, C.M. & Alessi, S.M. (1999). *Promoting a qualitative understanding of physics. Journal of computers in mathematics and science teaching, 18*, 439-457.
Planinic, M., Ivanjek, L., Susac, A., & Milin-Sipus, Z. (2013). Comparison of university students' understanding of graphs in different contexts. *Physical Review Special Topics – Physics Education Research, 9*, 020103. doi: 10.1103/PhysRevSTPER.9.020103
Ploetzner, R., Lippitsch, S., Galmbacher, M., Heuer, D., & Scherrer, S. (2009). Students' difficulties in learning from dynamic visualizations and how they may be overcome. *Computers in Human Behavior, 25*, 56-65. doi: 10.1016/j.chb.2008.06.006
Reif, F. (2010). *Applying Cognitive Science to Education: Thinking and Learning in Scientific and Other Complex Domains*. Cambridge: MIT Press.
Rieber, L.P. (1991). Animation, Incidental Learning, and Continuing Motivation. *Journal of Educational Psychology, 83*, 318-328. doi: 10.1037/0022-0663.83.3.318
Sanchez, C.A., & Wiley, J. (2010). Sex differences in science learning: Closing the gap through animations. *Learning and Individual Differences, 20*, 271-275. doi: 10.1016/j.lindif.2010.01.003
Sengupta, P., & Farris, A.V. (2012, June). Learning kinematics in elementary grades using agent-based computational modeling: a visual programming-based approach. In H. Schelhowe (Ed.), *Proceedings of the 11th International Conference on Interaction Design and Children* (pp. 78–87). New York, NY: ACM Press.
Smith, T.I., Wittmann, M.C., & Carter, T. (2014). Applying model analysis to a resource-based analysis of the Force and Motion Conceptual Evaluation. *Physical Review Special Topics – Physics Education Research, 10*, 020102. doi: 10.1103/PhysRevSTPER.10.020102
Thornton, R.K., & Sokoloff, D.F. (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. *American Journal of Physics, 58*, 858-867. doi: 10.1119/1.16350
Thornton, R.K., & Sokoloff, D.R. (1998). Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning

Laboratory and Lecture Curricula. *American Journal of Physics, 66*, 338-352. doi: 10.1119/1.18863

Titus, A.P. (1998). *Integrating Video and Animation with Physics Problem Solving Exercises on the World Wide Web* (Unpublished doctoral dissertation). North Carolina State University, Raleigh.

Trowbridge, D.E., & McDermott, L.C. (1980). Investigation of student understanding of the concept of velocity in one dimension. *American Journal of Physics, 48*, 1020-1028. doi: 10.1119/1.12298

Trowbridge, D.E., & McDermott, L.C. (1981). Investigation of student understanding of the concept of acceleration in one dimension. *American Journal of Physics, 49*, 242-253. doi: 10.1119/1.12525

Trudel, L. & Metioui, A. (2011, July). Conception of a computer-aided physics laboratory to facilitate the understanding of kinematical concepts. Paper presented at the *Proceedings of the 9th International Conference on Education and Information Systems, Technologies and Applications: EISTA 2011*. Orlando, Florida: International Institute of Informatics and Systemics.

Wieman, C.E., Adams, W.K., & Perkins, K.K. (2008). PhET: Simulations That Enhance Learning. *Science, 322*, 682-683. doi: 10.1126/science.1161948

Wright, B. D., & Linacre, J. M. (1994). Reasonable mean-square fit values. *Rasch Measurement Transactions, 8*, 370. Retrieved December 16, 2014, from http://www.rasch.org/rmt/rmt83b.htm

◈◇◈

APPENDICES

Appendix A: The constructed response items from our knowledge test

1. The given stroboscopic picture represents the motion of a ball from the moment it has been launched until the moment that precedes its impact with the ground. The length of the square's side within the diagram is 2 m, and the time interval between subsequent ball positions is 0.3 s. The ball is launched from the origin of the coordinate grid (x_0=0 m; y_0= 0 m). Determine the x-component of the ball's velocity, i.e. determine the rate at which the object covers the horizontal distance?

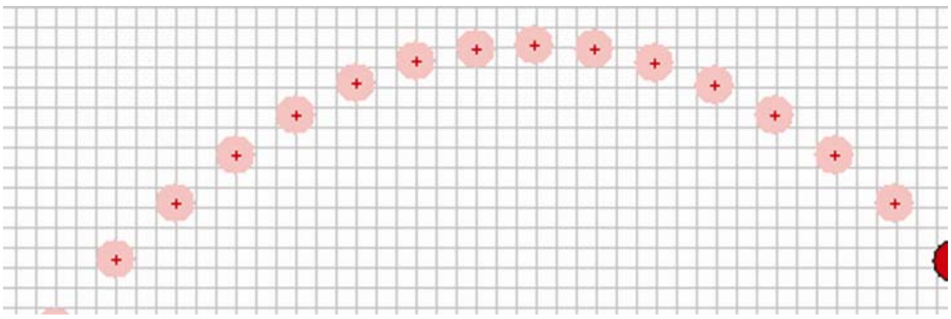

Figure A.1. Stroboscopic picture of ball's motion

2. Let us consider an object in uniformly accelerated rectilinear motion. The object starts at the moment t_0=0 s. At the moment t_1=5 s, the object is 50 m away from its starting point, and its velocity is 20 m/s. How far from its starting point will the object be at the moment t_2=7 s?

Appendix B: Survey on students attitudes towards learning and teaching of one-dimensional kinematics

I. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1: Strongly disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly agree

Table B.1 . Attitude survey instrument

1	The way we were taught one-dimensional kinematics made me interested in learning kinematics.	1 2 3 4 5
2	I feel that my knowledge of one-dimensional kinematics significantly improved through the lessons.	1 2 3 4 5
3	Despite the effort I made, for me it was hard to follow the one-dimensional kinematics lessons.	1 2 3 4 5
4	I learned physics with understanding within the one-dimensional kinematics lessons.	1 2 3 4 5
5	Problem solving in physics comes to memorizing the relevant physical formulas, and putting the given numerical values of physical quantities into these formulas.	1 2 3 4 5
6	There is always only one correct approach in physics problem solving.	1 2 3 4 5
7	Physics problem solving can be very fun.	1 2 3 4 5
8	Learning of one-dimensional kinematics comes to memorizing the facts and physical equations that are in the end solved by using mathematics.	1 2 3 4 5

II. What is your general impression of the one-dimensional kinematics lessons?

III. Question for the students who were taught kinematics through the Physlets or figure sequences:

I think that Physlets/sequences of simulation frames should be also used in other physics teaching units.

1 2 3 4 5