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TEACHING PHYSICS WITH SIMULATIONS: TEACHER-CENTERED VERSUS STUDENT-CENTERED APPROACHES

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Abstract. *Teaching and learning with simulations is widely used in today's classrooms. Therefore, it is important to examine the factors that potentially influence the effectiveness of simulation-based teaching environments. The aim of this research was to compare the effectiveness of teacher-centered and student-centered Physlet-based classes about one-dimensional kinematics at the level of upper-secondary school. The student sample consisted of 43 students (mostly 15-year-olds). Within the teacher-centered approach the teacher ran and controlled the simulations, and students watched the simulations on the projection screen. In the student-centered approach the students had the opportunity to work through the simulations on their computers. At the post-test, students from the teacher-centered approach outperformed their peers when it comes to conceptual understanding of kinematics, but students from the students-centered approach were more successful in solving quantitative problems. The results of this research support the idea that a progression from teacher-centered to student-centered approach may be optimal for learning novel concepts.*

Keywords: *cognitive load theory, teaching materials, teaching strategies, kinematics simulations*

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Introduction

Helping students to develop an understanding of physics concepts is a major goal of today's physics education. According to Greca & Moreira (1997) human beings develop understanding of the world by constructing mental models. Thereby mental models are perceived as analogical representations of reality whose main role is to allow for providing explanations and making predictions about the physical system they represent (Gentner & Stevens, 1983; Johnson-Laird, 1983).

Rapp and Kurby (2008) point out that development of mental models can be facilitated by use of external visualizations. Concretely, external visualizations may facilitate physics learning by: (a) highlighting elements that are most important to understanding the underlying physics concepts (b) conveying abstract information (c) providing a vivid context for testing hypotheses and solving problems.

Consequently, when selecting and/or designing pedagogically effective visualizations we have to ensure that these visualizations (Zou, 2000): (a) help the students to focus on key features of a problem (b) direct students to make predictions and inferences (c) bridge between daily-life and abstract concepts (d) do not generate high amounts of extraneous cognitive load.

In the context of physics instruction, it is particularly important to note that the effectiveness of visualizations largely depends on the extent to which visualizations trigger those cognitive activities that are considered to be of crucial importance for learning of the specific physics topic (Rapp & Kurby, 2008). A cognitive activity that is important for learning about most physics topics is establishing cause-and-effect relations. Consequently, construction of appropriate mental models of physical phenomena is facilitated if the learner is allowed to explore cause-and-effect relations for the modeled phenomena.

A type of visualization that facilitates exploring cause-and-effect relations are the interactive simulations. Simulations are generally defined as imitations of the operation of a real-world process or system over time (Banks, Carson, Nelson & Nicole, 2010). In interactive simulations the user is typically allowed to change some parameters of the simulated system and visualize the consequences of these changes.

Useful conclusions about design and use of simulations for physics instruction can be deduced from the cognitive load theory (CLT). According to cognitive load theory the human working memory has a relatively small capacity, i.e. it can hold approximately 5-7 chunks of knowledge at the same time (Shell *et al*, 2009). Consequently, for effective learning to occur the teacher has to work on preventing cognitive overload. In cognitive load theory we distinguish between three types of cognitive load – intrinsic load, extraneous load and germane load. The intrinsic load is related to the inherent complexity of the problem to be solved or information to be learned and it depends on the number and interactivity of elements which need to be simultaneously processed in the working memory (Sweller, 1994). On the other hand, extraneous load is caused by all the superfluous cognitive activities that do not contribute to construction of target knowledge. Finally, germane load is caused by cognitive processes that actively contribute to knowledge construction. It should be noted that these three types of load are additive and when managing cognitive load extraneous load must be reduced, intrinsic load must be adjusted, and germane load must be fostered (Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

In the context of teaching and learning with simulations germane load may be fostered by creating opportunities for exploration of cause-and-effect relations, as well as by selecting/designing simulations that trigger those specific cognitive activities that earlier physics education research recognized as crucial for learning of the corresponding physics topic. In addition, extraneous load can be lowered by avoiding simulations that include superfluous graphics, whereas the intrinsic load may be adjusted by segmentation of the topic to be learned into small subtopics. In order to prevent cognitive overload, it also highly desirable that the simulation includes a step-by-step control which allows the user to approach learning in small increments.

A simulation package whose features seem to be in line with the above-mentioned criteria are the Physlets. Physlets are small Java applets that had been created based on results of physics education research (Belloni & Christian, 2001). Unlike most other simulation packages for physics education, Physlets cover nearly all topics that are typically taught in introductory physics courses at the university level and they can be freely accessed at https://www.compadre.org/physlets. Besides, providing illustrations and explorations for all introductory physics topics, the Physlets package also includes physics problems in the simulation format, which is another distinguished feature of Physlets.

When it comes to Physlets about one-dimensional motion, it is important to note that they typically allow the learner to measure the objects' position at an arbitrary instant of time, which opens the opportunity for determining distances the objects travel in given time intervals, as well as for discussing about average velocities in these time intervals. All these activities are considered to be of key importance for learning kinematics (Arons, 1996) which could explain why Physlets-based instruction about kinematics proves to be more effective in comparison to traditional instruction characterized by use of static visualizations (Mešić, Dervić, Gazibegović-Busuladžić, Salibašić & Erceg, 2015).

However, generally the results of comparative studies on effectiveness of static and dynamic visualizations are mixed (Mayer, Hegarty, Mayer & Campbell, 2005). Certainly, the mixed results from earlier studies are partly due to differences in pedagogical approaches to using the static and dynamic visualizations in different studies.

According to Hattie (2009, p. 221) the effectiveness of learning with computers increases when: a) it is accompanied by the use of diverse teaching strategies b) there is pre-training in using computers as a tool for teaching and learning c) there are many opportunities for learning d) student is in control of learning e) peer learning and feedback are optimized.

Hattie also notes that there are many more studies that compare teaching in classes with and without computers than studies comparing different ways of using computers. Particularly rare are studies that compare effectiveness of learning environments in which dominantly teachers use the computer to environments in which students mostly use computers on their own (Hattie, 2009).

Today it is often believed that student-centered approaches to teaching are generally more effective in comparison to teacher-centered approaches (Catalano & Catalano, 1999; Redish, 2003). These beliefs mostly build on the principle of constructivism which states that learning can only occur as a result of learner's mental efforts, whereby the process of construction new knowledge largely depends on the learner's foreknowledge. Therefore, it is believed that learning is most effective when the learner has the opportunity to control the learning process (e.g. pace, choice of activities) on her/his own.

However, in their highly cited article on effectiveness of constructivist approaches, Kirschner, Sweller & Clark (2006) emphasize that there is much empirical evidence that guided instruction is generally more effective compared to minimal guidance approaches. By using the cognitive load theory framework, they provide strong arguments that advantage of guidance begins to recede only when learners come to the instruction with high level of foreknowledge which provides them "internal guidance".

Results of empirical studies about the effectiveness of learner-control in technology-based classrooms are mixed. Nimiec, Sikorski & Walberg (1996, p. 157) conducted a meta-analysis on learner-control (e.g., pacing and sequencing of instructional materials, reviewing, exploring) effects in computer aided instruction, whereby they concluded that "although learner control has theoretical appeal, its effects on learning seem neither powerful nor consistent". Similarly, Wu & Huang (2007) found that both, the teacher-centered and student-centered use of simulations, led to a significant (but nearly the same) improvement of students' understanding about the concepts of force and motion. However, a meta-analysis within the context of nursing education showed that learner-control leads to better learning in computer aided instruction (Cohen & Dacanay, 1994). Finally, there were also many researchers who found that teacher-centered approaches that emphasize direct guidance, lectures and demonstrations may be more effective than student centered approaches that allow students to engage in self-paced learning and to freely interact with technological tools. Concretely, Chang (2003) compared two computer-assisted approaches to science teaching whereby the teacher-directed approach proved to be significantly more effective than the student-centered approach when it comes to facilitating learning about science and developing positive attitudes. Moser, Zumbach & Seidl (2016) concluded that teacher-guidance is very important in simulation-based learning because working with simulations requires a relatively high level of metacognitive thinking. From the perspective of cognitive load theory, we could say that in the student-centered approach learning may be impeded due to the fact that students are not pre-trained in learning with simulations (Hattie, 2009). In such situations much of the working memory is probably allocated to cognitive processes related to handling the technical aspects of simulations instead to relevant learning.

Aim of the Present Research

From the presented review of relevant literature, it follows that the results of studies on effectiveness of learner-control in computer-assisted education are mixed. It seems that effectiveness of learner-control is potentially moderated by learners' foreknowledge, level of metacognitive knowledge, as well as by the mere nature of target knowledge and characteristics of the software package.

Physlets are widely used within the physics education community. Therefore, it could be generally important to study factors that moderate the effectiveness of Physlet-based teaching.

In this research, the aim was to compare the effectiveness of teacher-centered and student-centered Physlet-based classes about one-dimensional kinematics at the level of upper-secondary school. Concretely, the relative effectiveness of these two approaches in developing conceptual understanding of one-dimensional kinematics and ability to solve quantitative problems in kinematics was researched. The teacher-centered approach was mainly characterized by teacher-control of Physlets within a typical physics classroom environment in which students do not have multiple computers on their disposal. On the other hand, the student-centered approach was characterized by a higher-level of students' hands-on interaction with computers within a computer laboratory environment.

In schools with limited resources it proves to be difficult to get access to the computer laboratory. Therefore, it is potentially significant to explore whether Physlet-based teaching implemented in a computer laboratory is more effective than Physlet-based teaching implemented in a typical physics classroom.

Methodology of Research

Research Design

For purposes of studying the effectiveness of teacher-centered versus student-centered Physlet-based classes a quantitative research approach has been adopted. Concretely, a pre-post quasi-experimental design with two comparison groups has been implemented (Cook, Campbell, & Shadish, 2002).

For both groups the pre-test was implemented three days before beginning of the teaching treatment, and the post-test was implemented three days after the teaching treatment. The teaching treatment was conducted within the context of the regular curriculum. It lasted four teaching hours (three weeks) and covered the teaching topic of one-dimensional kinematics. The research was carried out in October and November 2017.

Participants

In our research the target population consisted of 15-year-old secondary school students. The sample of participants was obtained by means of the convenience sampling technique (Ari, Jacobs, Razavieh & Sorensen, 2009). Concretely, the research included two classes of students (N=43) who were enrolled in the *International Baccalaureate Middle Years Program* (IBMYP) at a Sarajevo gymnasium (Bosnia and Herzegovina). The IBMYP is a five-year programme intended for students aged 11-16 (Middle Years Programme, n.d.). Students, who participated in the research were mostly 15-year-olds, i.e. they were enrolled in the fourth year of the IBMYP. The sample included 26 girls and 17 boys.

In order to minimize the disruption of everyday school processes, a quasi-experimental instead of a true experimental design was chosen. One of the two classes has been randomly assigned to the teacher-centered (TC) treatment, whereas the other has been assigned to the student-centered (SC) treatment. The TC group included 20 students, whereas the SC group included 23 students. According to Gall, Gall & Borg (2003) in experimental research the recommended size of group is at least 15 per group.

Relevant Characteristics of the Curriculum

All the research participants have learned for the first time about one-dimensional kinematics in Year 8 of the primary school, i.e. as 13- year-olds. In Year 8, the focus of kinematics instruction is on the concepts of position, distance, speed, average velocity, acceleration, as well as uniform rectilinear motion and uniformly accelerated motion.

After Year 9 of primary school students from this research were directly enrolled in the fourth year of the IBMYP programme. Within the IBMYP curriculum students are expected to broaden and deepen their knowledge of one-dimensional kinematics concepts that they had already encountered in Year 8 of primary school. Concretely, they are expected to demonstrate a much higher ability of interpreting and using multiple representations of kinematics concepts and phenomena. This especially holds for interpreting graphs, using vectors and solving more complex quantitative problems. In this research four teaching hours have been allocated for the teaching unit „one-dimensional kinematics" (see Table 1).

Table 1. Schedule of research activities.

Number of teaching hours	Activity
1	Pre-test – Week 7 (after start of the school year)
2	Introduction to kinematics; Uniform motion (development and application of concepts) – Week 7-8
2	Uniformly accelerated motion (development and application of concepts) – Week 8-9
1	Post-test – Week 9 (after start of the school year)

Materials

Physlet–based learning materials were obtained from the Physlet physics book (Christian & Belloni, 2013) that can be freely accessed at: https://www.compadre.org/physlets/. In total, eighteen Physlets from the above mentioned book were used in the classes: five Physlet-illustrations (Illustration 2.1, Illustration 2.2, Illustration 2.3, Illustration 2.4, Illustration 2.5), six Physlet-explorations (Exploration 2.1, Exploration 2.2, Exploration 2.3, Exploration 2.4, Exploration 2.5, Exploration 2.8) and seven Physlet-problems (Problem 2.2, Problem 2.4, Problem 2.5, Problem 2.7, Problem 2.8, Problem 2.9, Problem 2.14).

The aim of illustrations was to vividly introduce the most important concepts of one-dimensional kinematics. On the other hand, explorations were supposed to facilitate learning by discovery, and problems were expected to provide effective contexts for elaboration and application of knowledge. Physlet-problems are believed to better resemble real-world problems (Christian & Belloni, 2001). Figure 1 shows a screenshot of a kinematics Physlet-problem.

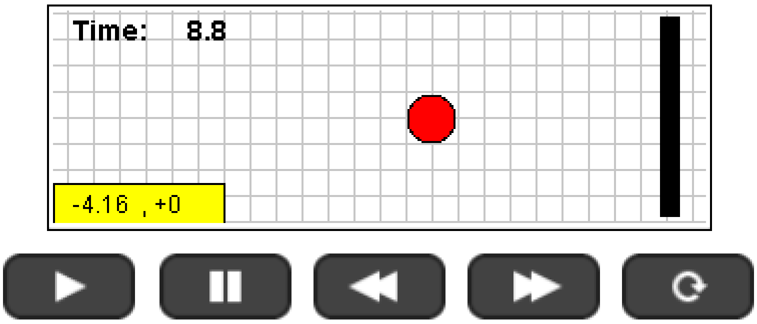

Figure 1: **Physlet-problem 2.2 – screenshot for t=8.8 s; x and y coordinates of the puck are shown.**

For the Physlet-problem from Figure 1 students are provided with the following textual description: "*A hockey puck sliding on ice collides and rebounds from a wall on a hockey rink. A top view is shown in the above animation (position is given in meters and time is given in seconds)*"**. Then the students are required to solve several tasks related to the described/simulated motion. For example, they are asked to** calculate the displacement, distance traveled, average velocity, and average speed of the puck for certain intervals of time (Δt_1=1.5 s to 12.0 s; Δt_2=1.5 s to 6.0 s; Δt_3=6.0 s to 12.0 s). In order to solve this part of Problem 2.2 one has to measure the puck's x-coordinate (they can do it with a left-click) at relevant instants of time. Based on the changes of the x-coordinate it is then possible to calculate the displacement and average velocity. In order to correctly solve this problem, students have to differentiate between concepts of distance and displacement, as well as between speed and velocity.

Teaching Treatments

In both treatments, the teacher firstly introduced the students with basic technical procedures relevant for using Physlets. Next, the above mentioned eighteen Physlets were used for facilitating learning about one-dimensional kinematics. For each subtopic firstly a Physlet-illustration has been discussed followed by Physlet-explorations and Physlet-problem activities.

Within the teacher-centered (TC) treatment the teacher ran the simulation, and the students watched the simulation on the projection screen. On the other hand, within the student-centered (SC) treatment the students followed the simulation on the projection screen and simultaneously worked through the simulation on their computers. The teacher provided the same explanations of Physlet-illustrations for both groups, but students from the SC group had the opportunity to directly interact with the simulation interface and to repeat simulations if they felt it was necessary. When it comes to Physlet-explorations, students from both groups got the same worksheets that were supposed to direct them through the exploration. In the TC group, the teacher ran the simulation and collected the relevant measurements, whereby in the SC group the students had the additional opportunity to collect the relevant measurements on their own. In both groups, the teacher led a similar discussion about the exploration and its findings. Finally, when it comes to Physlet-problems, in the TC group the teacher typically asked a student to demonstrate how she/he would solve the problem, whereby the other students were expected to follow the problem-solving process and solve the problem in their notebooks. When the teacher felt that the problem-solving process is heading into the wrong direction she attempted to provide guidance through asking corresponding questions. Within the SC group students were to a much more extent free to solve the Physlet-problem on their own – they had the opportunity to run and pause the simulations on their own, as well as to take measurements and to creatively explore all the features of the simulation interface. The teacher monitored the students' activities and when they were stuck she helped them out by asking corresponding questions.

Instruments

In this research conceptual understanding of kinematics has been operationalized through activities of predicting, explaining and interpreting kinematics phenomena. An important indicator of conceptual understanding of kinematics is also the ability to translate between multiple representations (Lichtenberger, Wagner, Hofer, Stern, & Vaterlaus, 2017). The assessment domain included all the concepts that were covered through instruction: position, displacement, speed, velocity, uniform motion, acceleration, uniformly accelerated motion. Eventually the **B**rief **O**ne-Dimensional **K**inematics **C**onceptual **S**urvey which consisted of 13 multiple choice-items was created. For each item there was a single correct answer, as well as four distracters. A short description of the BOKCS items is provided in Table 2.

Table 2. Short descriptions and sources of the BOKCS items are provided. Ordinal number of the item in the original instrument is given in parentheses.

Item 1	Item 2	Item 3	Item 4	Item 5
Assessing the misconception that equal position implies equal velocity	Comparing acceleration from motion diagrams of two objects	Relating a motion diagram to a v-t graph	Relating a motion diagram to a a-t graph	Calculating traveled distance from a v-t graph
FCI (19.)	FCI (20.)	MBT (1.)	MBT (2.)	TUG-K (4.)
Item 6	**Item 7**	**Item 8**	**Item 9**	**Item 10**
Assessing the „graph as picture of motion" misconception	Drawing conclusion about velocity from a x-t table	Drawing conclusion about type of motion from a v-t table	Drawing conclusion about velocity and acceleration from a v-t table	Calculating traveled distance from a v-t graph
TUG-K (8.)	Original	Original	Original	TUG-K (20.)
Item 11	**Item 12**	**Item 13**		
Assessing the misconception that negative coordinate implies negative velocity	Drawing conclusions about acceleration vector from information about velocity	Drawing conclusions about speed from the slope of x-t graph		
KCT (5.)	KCT (9.)	KCT (26.)		

It should be noted that 10 out of the 13 BOKCS items were adapted from widely known and extensively validated surveys that measure conceptual understanding of mechanical motion. Concretely, questions from **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 **K**inematics **C**oncept **T**est (Lichtenberger *et al*, 2017) have been selected. In addition, one should note that the selection of survey items was driven by the constructive alignment principle, i.e. the survey was designed to reflect as much as possible the most important ideas of the classes about one-dimensional kinematics. Consequently, from BOKCS scores one can draw valid conclusions about the level of students' understanding about one-dimensional kinematics.

It should be also noted that Cronbach's alpha for BOKCS amounted to 0.82 which means that BOCKS scores are characterized by a very good reliability (Bowling, 2005).

In the pre-test context, the students' ability to solve quantitative problems has been measured by a traditional quantitative problem which covered a situation that is typically taught in Year 8 of primary school (see Table 3). In the post-test context, the students' ability to solve quantitative problems has been measured by two context-rich problems. The decision to use context-rich problems in the post-test was related to the fact that this kind of problems cannot be solved by plug-and-chug approaches (Heller & Heller, 1999), as well as by the fact that students' level of knowledge at the post-test was expected to be at a higher level compared to the pre-test.

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Table 3. Quantitative problems that were used in this research.

Pre-test – Problem	An object performs uniformly accelerated rectilinear motion. It starts from rest at the moment t0=0 s. Between t1=7 s and t2=8 s the object travels 30 m. Find the acceleration of the object, as well as its velocity at t2=8 s!
Post-test – Problem 1	You are writing a short adventure story for your English class. In your story, two submarines on a secret mission need to arrive at a place in the middle of the Atlantic ocean at the same time. They start out at the same time from positions equally distant from the rendezvous point. They travel at different velocities, but both go in a straight line. The first submarine travels at an average velocity of 20 km/h for the first 500 km, 40 km/h for the next 500 km, 30 km/h for the next 500 km and 50 km/h for the final 500 km. In the plot, the second submarine is required to travel at a constant velocity, so the captain needs to determine the magnitude of that velocity.
Post-test – Problem 2	In your new job, you are the technical advisor for the writers of a gangster movie about Bonnie and Clyde. In one scene Bonnie and Clyde try to flee from one state to another. (If they got across the state line, they could evade capture, at least for a while until they became Federal fugitives.) In the script, Bonnie is driving down the highway at 108 km/h and passes a concealed police car that is 1 kilometer from the state line. The instant Bonnie and Clyde pass the patrol car, the cop pulls onto the highway and accelerates at a constant rate of 2 m/s2. The writers want to know if they make it across the state line before the pursuing cop catches up with them.

Note. Post-test problems were adapted from: http://groups.physics.umn.edu/physed/ Research/ CRP/on-lineArchive/ola.html

Data Analysis

For each correctly answered BOKCS item students were awarded one point. Consequently, the BOKCS scale ranged from 0 to 13. Students' solutions to quantitative problems were analyzed by means of a scoring rubric. The maximum score for each of the quantitative problems was set to 25. Thereafter students' responses were entered into a database with the purpose of conducting corresponding statistical analyses. We attempted to answer our research questions by conducting analyses of covariance. Furthermore, the post-test between-group differences on individual quantitative problems have been checked by the Wilcoxon rank-sum test. Finally, the relationship between conceptual understanding and problem-solving ability has been explored through correlational analyses.

Results of Research

Students' Conceptual Understanding of One-dimensional Kinematics

A first insight into the relative effectiveness of the two teaching treatments when it comes to developing conceptual understanding of kinematics can be gained through comparison of average scores on pre-test and post-test (see Table 4).

Table 4. Average scores on BOKCS pre-test and post-test. Standard deviations are given in parentheses. The maximum of the BOKCS scale was 13.

	Teacher-centered approach	Student-centered approach
Pre-test	3.50 (2.82)	4.3 (3.00)
Post-test	6.55 (2.84)	5.22 (3.74)

Based on the pre-test and post-test scores, the class average normalized gain was calculated (see Smith, Wittmann & Carter, 2014). It amounted to .32 in the TC group and .11 in the SC group.

In the next step, it has been decided to conduct an analysis of covariance (ANCOVA) for purposes of testing for statistical significance of between-group differences on the post-test, while controlling for differences on pre-test. Firstly, the statistical assumptions of ANCOVA have been checked. Concretely, it has been shown that the data met the most important assumptions of ANCOVA: homogeneity of variances, independence of covariate and treatment, homogeneity of regression slopes and normal distribution of post-test scores for each of the groups.

The results of ANCOVA showed that there was a statistically significant effect of teaching treatment on students' understanding of one-dimensional kinematics after controlling for pre-test differences, $F(1, 40)=9.21$, $p<.01$, partial η^2 (eta squared)=.19. In other words, the teacher-centered treatment proved to be significantly more effective than the student-centered approach when it comes to developing conceptual understanding. In the TC group the adjusted post-test mean was 2.04 higher which corresponds to a difference of 15.7 %.

Students' Ability to Solve Quantitative Problems in One-dimensional Kinematics

A first insight into the relative effectiveness of the two teaching treatments when it comes to developing students' problem-solving ability can be gained through comparison of average scores on the pre-test and post-test problems (see Table 5).

Table 5. Average scores on quantitative problems from pre-test and post-test. Standard deviations are given in parentheses. For each problem the maximum score was set to 25.

	Teacher-centered approach	Student-centered approach
Pre-test – problem	3.15 (2.41)	5.87 (3.68)
Post-test – problem 1	9.05 (10.27)	20.78 (7.13)
Post-test – problem 2	5.70 (6.61)	8.74 (9.01)
Post-test – composite score	14.75 (14.53)	29.52 (12.63)

Wilcoxon rank-sum test of between-group differences on individual post-test items showed that students from the SC approach significantly outperformed their peers from the TC approach on Problem 1, W_s=637, z=3.35, p=.001. On the other hand, for Problem 2 no statistically significant between-group differences have been detected, W_s=542, z=0.9, p=.37.

For purposes of exploring between group differences on the composite score an ANCOVA has been conducted. The results of ANCOVA showed that there was a statistically significant effect of teaching treatment on students' ability to solve post-test problems after controlling for pre-test differences, F(1, 40)=9.13, p<.01, partial η^2 (eta squared)=.18. In other words, the student-centered treatment proved to be significantly more effective than the teacher-centered approach when it comes to developing ability to solve quantitative kinematics problems. In the SC group the adjusted post-test mean was 13.8 points higher which corresponds to a difference of 27.6 %. However, these results should be taken with caution because the data violated the independence of covariate and treatment assumption of ANCOVA.

For that reason, additional analyses of between-group differences on the problem-solving measure have been conducted. Concretely, for students who scored 5 points (in both groups 5 points was the most frequent score on post-test) on the pre-test problem, the results on the post-test problems have been compared (see Table 6).

Table 6. Average score on post-test problems for students who scored 5 points on pre-test problem. Standard deviations are given in parentheses.

	Teacher-centered approach (n=12)	Student-centered approach (n=10)
Post-test – composite score	11.08 (11.09)	26.90 (11.74)

Results of the independent t-test for data from Table 6 show that students from the SC approach significantly outperformed their peers from the TC group on solving quantitative problems, t(20)=3.24, p<.01.

Relationship between Conceptual Understanding and Ability to Solve Quantitative Problems

An insight into the relationship between conceptual understanding and ability to solve quantitative problems in kinematics can be gained through correlational analyses (see Table 7).

Table 7. Correlation between conceptual understanding and problem-solving ability at post-test.

	Post-test – problem 1	Post-test – problem 2	Post-test – composite score
TC – conceptual understanding at post-test	r=.51, p=.02	r=.25, p=.29	r=.48, p=.03
SC – conceptual understanding at post-test	r=.19, p=.38	r=.77, p<.001	r=.65, p=.001
Overall – conceptual understanding at post-test	r=.15, p=.32	r=.54, p<.001	r=.39, p=.01

It should be noted that in both subgroups students' overall performance on quantitative problems was significantly correlated with conceptual understanding on post-test.

Discussion

From BOKCS pre-test scores it follows that students from both groups entered the teaching treatment with a relatively low level of conceptual understanding of one-dimensional kinematics. BOKCS items required the students to engage in activities of interpreting motion diagrams, graphs and tabular representations, as well as to translate between different representations. Consequently, low pre-test scores on BOKCS indicate that in Bosnia and Herzegovina students enter upper secondary school with low representational knowledge about kinematics of one-dimensional motion which is in line with the findings from the study by Mešić *et al.* (2015). Three days after the pre-test, the students received the teaching treatments which lasted four teaching hours. Within these treatments students observed one-dimensional motion, often accompanied with real-time graphing and real time construction of tabular representations and motion diagrams. In the SC group, students also had the opportunity to take measurements on their own and to more actively engage in the process of Physlet-problem solving. However, even at the post-test the BOKCS scores for both groups were relatively low (TC – 50.4 %; SC – 40.1 %) which is in line with the idea that conceptual change is a process of gradual transformation of knowledge which often takes considerable time (Jonassen, Strobel & Gottdenker, 2005; Ketamo & Kiili, 2010;). The class average normalized gain for the TC group proved to be of medium size, whereas the normalized gain for the SC group can be categorized as low (Hake, 2002). A similar normalized gain for teacher-centered Physlet-based classes about one-dimensional kinematics has been obtained in the research by Mešić *et al* (2015).

Results of ANCOVA showed that the teacher-centered approach was significantly more effective than the student-centered approach when it comes to developing students' conceptual understanding of one-dimensional kinematics. The corresponding effect size can be considered as large (Pallant, 2011). These results are in line with the findings from the research on simulation-based science learning conducted by Chang (2003), as well as with the basic principles of cognitive load theory (Kirschner, Sweller & Clark, 2006). As a matter of fact, according to Kirschner, Sweller & Clark (2006) novel information is best learned when there is high degree of teacher-control, and advantage of guided instruction only begins to recede when learners have a high degree of foreknowledge. In the research by Moser, Zumbach & Seidl (2016) teacher guidance proved to be important for simulation-based learning about the principle of energy conservation. Concretely, they emphasized the importance of scaffolding and metacognitive prompting when using simulations in physics classrooms. In the SC approach the students learned with Physlet-illustrations and explorations by following simulations from the projection screen *and simultaneously* working through simulations on their computers. This could have induced extraneous cognitive load through the split-attention effect which occurs in situations where students have to focus attention on spatially (projection screen vs computer screen) distant stimuli (Ayres & Sweller, 2005). Learning with new technologies (Physlets) certainly induced extraneous load in both groups, but it was more pronounced within the SC approach because of the above mentioned split-attention effect, as well as because of handling technical aspects (hands-on interaction) of using the Physlets.

Next, the results of this research indicate that the student-centered Physlet-based classes are more effective in promoting the students' ability for solving quantitative problems in kinematics. In addition, correlational analyses show that there was a moderate to large association between students' conceptual knowledge and problem-solving scores. This finding is in line with the conclusions about the relationship between conceptual and procedural knowledge from the study by Surif, Ibrahim & Mokhtar (2012). According to Cracolice, Deming & Ehlert (2008) effective problem solving requires both, the application of conceptual knowledge, as well as application of procedural knowledge. Problem 1 from the post-test required reasoning about average velocity and uniform motion, unlike Problem 2 which required the students to combine knowledge of uniform and uniformly accelerated motion. In other words, the required level of conceptual knowledge was higher for Problem 2, whereas the required level of procedural knowledge was similar in both cases. According to Pirttima, Husu & Metsarinne (2017) students mainly construct procedural knowledge through hands-on activities. In this research, the main difference between the TC and SC approach was related to the fact that SC students learned about kinematics in a computer laboratory, where they had the opportunity for hands-on interaction with computers. This direct interaction with computers proved to be particularly important within the phase of elaboration of knowledge where students were supposed to apply what they have learned, i.e. to solve Physlet-problems. Within a typical physics classroom (TC approach) students do not have the opportunity to solve Physlet-problems on their own which probably has a negative impact on the development of procedural knowledge that is important for problem solving in physics. It seems that Problem 1 could be solved even by students with relatively low level of conceptual knowledge and medium level of procedural knowledge, whereas Problem 2 required relatively high level of conceptual knowledge and medium level of procedural knowledge. Between-group differences on the problem-solving measure primarily stem from differences on Problem 1. As a matter of fact, only 5 out of 20 students from TC approach scored 20 points and above at Problem 1, whereas there were even 18 out of 23 such students in the SC approach. Taking into account the fact that students from the TC approach achieved a better result on BOKCS, it seems that between-group differences on Problem 1 indicate a higher level of procedural knowledge in the SC group. On Problem 2 the between-group differences did not prove to be statistically significant. From a statistical perspective, this can be explained by the fact that Problem 2 was found to be very difficult for students from both groups which led to the difference score being very low. It should be noted that the higher level of difficulty of Problem 2 was mainly related to its higher conceptual complexity. In both groups there was only a small proportion of students who had a high level of conceptual understanding, as well as (at least) a medium level of procedural knowledge.

The results of this research indicate that a progression from teacher-centered to student-centered activities could be optimal for Physlet-based teaching. For a more effective development of problem-solving skills it is recommended to organize learning sessions in the computer lab.

When it comes to possible limitations of this research it should be noted that the relatively small sample size (N=43) which was obtained by conventional sampling could raise concerns about the external validity of the conclusions. However, it should be noted that the obtained conclusions about the effectiveness of TC approach are in line with findings from a similar study conducted by Mešić *et al* (2015) which lowers the probability on non-representativeness of the used sample. In addition, it is important to note that in the ANCOVA on problem solving differences the assumption of independence between covariate and treatment was violated. Analyses that were conducted with the aim to resolve this issue are based on relatively small samples. However, from a statistical perspective there are no objections to using the t-test on samples that are even lower than 5 (de Winter, 2013). Finally, a more intensive pre-training on using the Physlets could have reduced the level of extraneous load, particularly for the SC group (Hattie, 2009).

Conclusions

Physlet simulations are often used in today's physics classrooms. Due to the fact that many schools have limited resources for teachers who use Physlets, it is of high practical importance to know whether implementing Physlets in the computer lab is significantly more effective than implementing Physlets in the classroom.

From the results of this research it can be concluded that using Physlets in a teacher-centered physics classroom can be even more effective than using Physlets in a student-centered computer lab if the only goal is developing basic conceptual understanding in novices. This finding can be primarily accounted for by the split-attention effect which may occur due to simultaneous observing of simulations on the projection and computer screen. However, from the results of this research it also follows that using Physlets in a student-centered computer lab may be more effective in developing the students' ability to solve quantitative, real-world problems which is in line with the idea that procedural knowledge is best promoted through hands-on activities.

When it comes to practical implications of this research it should be emphasized that for teaching with Physlets a progression from teacher-led to student-led activities is recommended. Concretely, development of initial

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conceptual understanding can be most effectively organized through implementation of Physlet-illustrations and explorations in the physics classroom. On the other hand, the potential of Physlet-problems is more effectively utilized in student-centered approaches which allow the students to take measurements and manipulate simulation parameters on their own. Such environments are more successful in promoting development of procedural knowledge which is of crucial importance for problem solving. Consequently, it is advisable that teachers occasionally move their physics classes to the computer-lab environment, at least within the context of some review lessons.

In future research, it may be useful to further explore the factors which potentially moderate the effectiveness of Physlet-based teaching, such as the level of students' computer skills and metacognitive knowledge, as well as the characteristics of teacher guidance.

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