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THE EFFECTS OF LABORATORY INQUIRE-BASED EXPERIMENTS AND COMPUTER SIMULATIONS ON HIGH SCHOOL STUDENTS‘ PERFORMANCE AND COGNITIVE LOAD IN PHYSICS TEACHING*

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Abstract. The main goal of this study was to examine the extent to which different teaching instructions focused on the application of laboratory inquire-based experiments (LIBEs) and interactive computer based simulations (ICBSs) improved understanding of physical contents in high school students, compared to traditional teaching approach. Additionally, the study examined how the applied instructions influenced students' assessment of invested cognitive load. A convenience sample of this research included 187 high school students. A multiple-choice test of knowledge was used as a measuring instrument for the students' performance. Each task in the test was followed by the five-point Likert-type scale for the evaluation of invested cognitive load. In addition to descriptive statistics, determination of significant differences in performance and cognitive load as well as the calculation of instructional efficiency of applied instructional design, computed one-factor analysis of variance and Tukey's post-hoc test. The findings indicate that teaching instructions based on the use of LIBEs and ICBSs equally contribute to an increase in students' perform-

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ance and the reduction of cognitive load unlike traditional teaching of Physics. The results obtained by the students from the LIBEs and ICBSs groups for calculated instructional efficiency suggest that the applied teaching strategies represent effective teaching instructions.
Keywords: Physics teaching, computer based simulations, laboratory inquire-based experiments, students' performance, cognitive load.

INTRODUCTION

Teaching practice shows that the educational process at schools in the Republic of Serbia is generally implemented in the traditional way, where a teacher dominates in the classroom, while a student has a passive role that requires a reproduction of memorized facts. The main reason for such situation is inertness and unwillingness of teachers to adopt innovative strategies as a basic and daily requirement of the educational process (Adamov, Segedinac, Halaši & Olić, 2015). In order to eliminate the negative effects of such education system, in recent years there have been perceived attempts to change the school, insisting on the creation of conditions that promote new approaches in teaching and learning in order to advance the quality of teaching and improve the knowledge and motivation of students to learn. In terms of contemporary teaching of natural sciences, there is no longer the question of whether to apply the models of work that imply the use of laboratory inquire-based experiments and computer technology, but the main task is to reach the appropriate solutions, as well as how to apply them in the context of certain subject contents, in order to make learning more efficient.

Since teaching science is generally based on concepts, laboratory inquire-based experiments and observations should become a constituent part of instruction in the classroom, providing students to visualize these concepts in their minds. The results of using experiments in Physics teaching are the following: better understanding of natural phenomena, identification and understanding of cause-and-effect relationship of natural phenomena, development of concepts based on the principle from simple to complex, adoption of permanent knowledge in relation to traditionally acquired knowledge, transformation of the acquired knowledge into skills and habits, etc. (Obradović & Rančić, 2012). Inquire-based experiments serve to lead students to question the contradictions they form in their minds, and attach meaning to concepts in this way (Gunstone & Champagne, 1990). In other words, students become aware of phenomena occuring in nature, question them, and experiment to test their way for finding solutions.

The advance of information and communiction technologies in today's world necessitates their use in the physics teaching as well. Computer simulations, as a teaching material supported by ICT technology, have become increasingly powerful and available to teachers in the past three decades (Trundle & Bell, 2010). Currently, there is a wide range of simulations available on Internet, which could be used by physics teachers at classes when they teach lectures and carry out experiments. Computer simulations offer idealized, dynamic and visual representations of physical phenomena and experiments which would be dangerous, costly, or otherwise not feasible in school laboratory (Hennessy, Wishart, Whitelock, Deaney, Brawn, Velle, McFarlane, Ruthven & Winterbottom, 2007). Since the computer simulations show simplified versions of the natural world, they can focus students' attention more directly on the desired phenomenon (de Jong & Van Joolingen, 1998; Perkins, Adams, Dubson, Finklestein, Reid & Wiemen 2006; Wiemen, Perkins & Adams, 2008). Additionally, computer simulations may allow students to visualize objects and processes that are normally beyond the users' control in the natural world (de Jong, Linn & Zacharia, 2013). They allow students to confront their own beliefs by working with and receiving immediate feedback about original and/or real data, and making personalized problem-solving decisions (Hargrave & Kenton, 2000; Lee, 1999). In comparison with textbooks and lectures, a learning environment with a computer simulations has the advantages that students can systematically explore hypothetical situations, interact with a simplified version of a process or system, change the time-scale of events, and practice tasks and solve problems in a realistic environment without stress (Rutten, van Joolingen & van der Veen, 2012). According to Psycharis (Psycharis, 2011), effective computer simulations are built upon "mathematical models' in order to accurately depict the phenomena or processes to be studied, and a well-designed computer simulations can engage the learner in interaction by helping the learner to predict the course and results of certain actions, understand why observed events occur, explore the effects of modifying preliminary conclusions, and stimulate critical thinking.

There are numerous research studies that have examined instructional efficiency of the laboratory inquire-based experiments and computer simulations in physics teaching (as shown in the Literature Review). In majority of these studies, the instructional efficiency of different approaches has been measured by assessing the students' achievement, without assessing the invested cognitive load. Cognitive load could be generally defined as a requirement for working memory resources necessary for fulfilling the goals of the cognitive activities in certain situations. There are three types of cognitive load: intrinsic, extraneous and germane cognitive load (Paas, Tuovinen, Tabbers & Van Gerven, 2003; Sweller, Ayres & Kalyuga, 2011). Intrinsic cognitive load is caused by internal or intellectual complexity of the task of teaching material. Intrinsic cognitive load can not directly alter due to use of different instructional approaches. According to Clark, Nguyen and Sweller (2006) only way to manage the intrinsic load is decomposing complex tasks into a series of prerequisite tasks and supporting knowledge distributed over a series of topics or lessons. Unlike the intrinsic cognitive load, extraneous and germane cognitive load can be affected because they are under the influence of a direct way of teaching.

The instructional efficiency of a teaching method measured by a combination of the students' performance and invested mental effort was introduced by Paas and Van Merrienboer (Paas & Van Merriënboer, 1993). Their calculation yields a two-dimensional instructional efficiency measure, and its successful implementation has been widely documented in the literature (Kalyuga, Chandler & Sweller, 1999; Kalyuga, Chandler & Sweller, 2000; Kalyuga, Chandler & Sweller, 2001; Pass *et al*., 2003; Plass, Moreno & Brunken, 2010; Tindall-Ford, Chandler & Sweller, 1997).

Therefore, it could be considered that it is necessary to conduct a research on the instruction efficiency of laboratory experiments and simulation measured by the achievement and cognitive load in the implementation of particular Physics contents in relation to the traditional teaching. *The main goal of this research* was to examine the extent to which different instructional approachers focused on the application of LIBEs and ICBSs improved understanding of physical contents in the high school students, compared to traditional teaching approach, as well as to examine how the applied instructions influenced students' assessment of invested cognitive load.

LITERATURE REVIEW

A number of the research studies confirm the thesis that the experimental work (inquire-based experiments, hands-on experiment and practical activities) should have a key role in learning and teaching Physics. Inquire-based experiments and practical activities in Physics, improve students' learning, help development of practical skills, problem solving, analytical skills, and positive attitudes toward science (Cziprok, Popescu, Pop & Variu, 2015). In addition to the aforementioned effects of the application of experiments in the Physics teaching, Azar & Sengulec (2011) emphasized as the most important engender permanence of knowledge. No doubt, through inquire-based experiments, students become active learners and acquire scientific knowledge and skills in a meaningful context (Benson & Nkiruka, 2013). Comparing the efficacy of the inquire-based experiments and traditional approach in science teaching, inquire-based experiments had positive effects on students' cognitive development, self-confidence, science achievement, science process skills, and conceptual understanding of science knowledge as a whole in comparison to the traditional approach (Butts, Koballa & Elliot, 1997; Ertepinar & Geban, 1996; Gibson & Chase, 2002). A number of papers published in this field in the Republic of Serbia is minor. In physics teaching, Kuka (1999) compared the laboratory experiments and classical traditional teaching by determining the level of knowledge acquisition (knowing of the facts, understanding the concepts, and application of knowledge) and permanence of the knowledge. The research was carried out in the seventh and the eighth grade of elementary school. The experiment included eight classes. The experimental classes achieved significantly better results both concerning all three levels of knowledge and concerning permanence of the acquired knowledge in comparison to the control classes.

Although laboratory experimental activities have long (thirty years) tradition, and a distinctive and central role in the science curriculum, they are still not applied sufficiently in the Republic of Serbia according to research TIMSS 2007 (Verbić, Bojović & Milin, 2011). The reasons for inappropriate application of experiments in Physics teaching in our schools are probably the following: lack of functional Physics laboratory, inappropriate equipment for Physics practical activities, insufficient knowledge of Physics teachers to apply laboratory inquire-based experiments in class, not recognizing the importance of using the experiments in teaching Physics, or a lack of teachers' motivation for more meaningful implementation of the instruction. These may be contributing to low level of performance of students in Physics, which has been confirmed in all previously implemented TIMSS research.

In order to overcome negative effects of the lack of laboratory experiments on students' learning outcomes in teaching Physics, multiple studies have emphasized a positive effect of using computer simulations and experiment animations in enhancing learning of Physics. Many of these studies are focused on knowledge acquisition of specific contents: in mechanics (Gorsky & Finegold, 1992), kinematics (Grayson & McDermott, 1996), electric circuits (Azar & Sengülec, 2011; Lea, Thacker, Kim & Miller, 1996; Ronen & Eliahu, 2000), electricity (Jaakkola & Nurmi, 2008), optics (Eylon, Ronen & Ganiel, 1996; Goldberg, 1997), waves (Grayson, 1996), thermal Physics (Russell, Lucas & McRobbie, 2004). Tao and Gunstone (1999) argued that simulations had the additional advantage since they required from students to inquire into the presented event, alter values of variables, initiate processes, probe conditions, and observe the results of these actions. Although the conducted studies included simulations which contributed to improving Physics education, other investigations reported less impressive results in the use of computer simulations in science teaching (Sarabando, Cravino & Soares, 2014; Steinberg, 2000). Further investigation also showed that the use of computer simulations was less effective than the traditional instruction and laboratory inquire-based experiments (Marshall & Young, 2006). Despite high expectations for the computer simulations, it is not possible to guarantee a general conclusion about their effectiveness (Yaman, Nerdel & Bayrhuber, 2008).

An important factor which influences the efficiency of the instructional approach (either laboratory inquire-based experiments or interactive computer based simulations) is a nature of the contents which has been taught. In order to test the instruction efficiency LIBEs and ICBs in Physics teaching by assessing the students' achievement and their cognitive load, there was chosen a teaching topic *Surface Energy and Surface Tension* as suitable for the realization of the aforementioned instruction. We selected the teaching topic Surface Energy and Surface Tension based on empirical data obtained from interviews with Physics teachers from the high schools in Novi Sad and

Subotica, which showed that students had difficulties to understand the way of presentation of liquid surface as tensioned membrane.

METHODOLOGY

Research Design. The experimental research design followed by researchers was the pretest/posttest equivalent groups design. The experimental groups (E1 i E2) consisted of students from one school, while the control group (C) consisted of students from another school. Hence the students from experimental and control groups did not communicate with each other. Since students of E1 and E2 groups attended the same school, their potential mutual communication represented a limitation of the study. At the beginning of the research, all three groups of students showed equal average score achieved in the pretest, which made them equivalent. During the research, the experimental groups differed by the applied treatment (an instructional approach). LIBEs teaching was applied in the experimental group of students (E1), ICBSs was applied in the second experimental group of students (E2) and the traditional teaching was applied in the control group of students (C). One the same teacher of physics, who is a coauthor of this paper, taught three groups of students by presenting the teaching contents 'Surface Energy and Surface Tension' in three different instructional approaches (the process of work was described in the *Research Procedure*). Upon the finalization of the content teaching, students from all three groups took the final test in the same day.

Research Questions. In line with the aim of the research, the following research questions have been formulated:

1. Do the instructional approaches based on the application of LIBEs and ICBSs increase students' performance in the field of Surface Energy and Surface Tension, compared to traditional teaching approach?
2. Do the instructional approaches based on the application of LIBEs and ICBSs reduce extraneous cognitive load that needs to be invested while solving problems in the field of Surface Energy and Surface Tension, compared to traditional teaching approach?
3. Based on the obtained results of the students' performance and their self-assessment of their invested mental effort, as an aspect of cognitive load, it is necessary to determine which teaching strategies are effective models for teaching Physics. Based on this self-assessment of cognitive load, it is necessary to determine which teaching strategies are efficient models for learning Physics.

Participants. A sample of convenience consisted of 187 students in six classes, from two Mathematics and Science High Schools from Novi Sad, Serbia. In total, every experiment group (E1 and E2) consisted of 61 students, while C group consisted of 59 students. The respondents were in their second school year and their age was from 16 to 17. In order to calculate the sample size we used the application http://www.raosoft.com/samplesize.html. The maximum sample of all the students of Mathematics and Science High Schools from Novi Sad was around 300 students, and our sample of 187 students represented a convenience sample), since it was in range from 169 to 207 students. The range borders were defined with the confidence level of 95%, i.e. 99%.

Research Instruments. The instruments which were designed and applied in the research were the pretest and the posttest. The tests measured students' knowledge and mental effort as an aspect of cognitive load. Each of the two applied tests was in the form of a multiple-choice test and contained 10 tasks. All the tasks consisted of four distractors respectively and the one keyed response. In each test, every correctly solved task was scored with two points, so the maximum possible achievement per test was 20 points.

The first test (pre-test) tested the students of E1, E2 and C groups in order to synchronize previous knowledge of students in all three groups. This test covered the topic Fluid Mechanics. The second test (post-test) was conducted after the implementation of the topic Surface Energy and Surface Tension in different teaching instructions in E1, E2 and C groups, and it tested the knowledge in this topic.

Pre-test and post-test assurance parameters were evaluated by three university professors which were experts in the field of Physics teaching methodology, three Physics teacher and one Psychology teacher. The applied measuring instruments indicated satisfactory metric characteristics. The internal consistency expressed by Cronbach α coefficient for post-test was 0.7, indicating acceptable reliability (Loewenthal, 2001). To determine the quality of the post-test, there was also calculated the item difficulty index (P). The average value difficulty index was 0.51 for the final measuring. It means that applied post-test contained the tasks if the acceptable level of difficulty (Ding, Chabay, Sherwood & Beichner, 2006).

In this study, there has been applied a method of self-evaluation, one of the mostly used methods for measurement of cognitive load (de Jong, 2010; de Waard, 1996; Paas *et al*., 2003; Sweller, Ayres & Kalyuga, 2011). Regarding its measurement, cognitive load could be conceptualized in the dimensions of mental load, mental effort, and performance (Choi, van Merriënboer & Paas, 2014). According to Choi *et al.* (2014), mental effort is considered a human-centered dimension, which refers to the amount of capacity or resources, which is actually allocated by the learner to accommodate the task demands. Therefore, we have chosen the particular cognitive load assessment based on mental effort. This method belongs to the group of empirical indirect subjective measures. Regarding this method, students themselves evaluate their mental effort during studying, according to given Likert scale (de Jong, 2010). The studies (Ayres, 2006; Kalyuga, Chandler & Sweller, 2000; Kalyuga, Chandler & Sweller, 2001; Paas & Merriënboer, 1994) have emphasized that the mentioned scale is the most reliable and the most sensitive in detecting relatively small differences in mental effort. Another advantage of self-rating scales is the fact that they do not intefere with the task performance as the other methods do (Kalyuga, Chandler & Sweller, 2001). Accordingly, in this study each task on the post-test was followed by the Five Point Likert-type Scales with descriptors: very easy (code 1); easy (code 2); neither easy nor difficult (code 3); difficult (code 4); very difficult (code 5). For each task, students were asked to evaluate the mental effort they invested during their solving the tasks.

Data collection and procedure. The experiment was carried out in the school year 2013/2014, during regular Physics classes, on the contents of the lesson subtopic Surface Energy and Surface Tension, in the second semester of the second grade of high school. At the beginning of the research, prior to teaching the subtopic Surface Energy and Surface Tension, two experimental and one control group of students were tested with the pretest in order to synchronize previous knowledge of students in all three groups. After pretesting, teaching of the subtopic Surface Energy and Surface Tension was implemented with the experimental models in Group E1 (LIBEs) and Group E2 (ICBSs), and the control model in Group C.

In *Group E1 (LIBEs)* there was used Physics equipment for hands-on experiment. The teacher first explained the task of the experiment. The students were grouped. Four students were assigned to each group. Each group was given a required utensils for the experiment, and set up the experiment according to the teacher's instructions. During the experiment the teacher was actively interfered in what the students were doing, directing them to the proper explanations of observed phenomena (surface tension, capillary phenomena). Students were asked to present their observations on each task of the experiment in the notebook. In the final part of the class, each group of students presented the results of their work and actively participated in discussions related to the teaching topic.

During the instruction in *Group E2 (ICBSs),* the teacher first presented appropriate online computer simulations and animations (2 28 Surface Tension; Surface Tension; 7.2 Surfactants and Surface Tension). Then, the students were encouraged to express their observations in relation to the presented simulations and animations, and asked to explain observed physical phenomena. In this part of the class the teacher had the role of a facilitator and a guide, directing students to proper explanations of the phenomena. Then the students in a dialogue with the teacher made the connection between the observed phenomena and the physical phenomena, which occur in the everyday life (the life of insects on the liquid surface; oil droplets on the water surface; a soap bubble).

Group C: Teaching the topic Surface Energy and Surface Tension was implemented in the traditional instruction, including the instructional strategies: frontal lectures, discussion and intermittent asking questions by the teacher, and responding by students. Teaching aids and devices used in the research were a textbook, blackboard and chalk.

At class, after the implementation of the topic Surface Energy and Surface Tension in different ways, the posttest was conducted in all three groups of students at the same time, with the aim of analyzing differences in the achievement and cognitive load among the groups of students concerning the topic.

Data Analysis. In addition to the descriptive statistics, determination of significant differences in performance and cognitive load, as well as the calculation of instructional efficiency of applied instructional design, computed one-factor analysis of variance and Tukey's post-hoc test. All analyses were conducted in SPSS 12.0 software.

Limitations and delimmitations. The following limitations could be observed regarding this study:

(1) Samples were selected by a convenience sampling procedure.
(2) This study included only two high schools and contents of Surface Energy and Surface Tension for the second grade of high school in the Republic of Serbia. Accordingly, the results cannot be generalized to other physical topics.
(3) Students from the experimental groups were required to have greater activity and harder work during the research, in comparison to students from the control group.
(4) Students from all three groups were informed in advance that their achievement was going to be tested by the knowledge tests after the implementation of the topic Surface Energy and Surface Tension.
(5) We used mental effort as an aspect of cognitive load, while indirect method of subjective measure was applied for measuring.
(6) Knowing the mental effort, the instructional efficacy was calculated, which was the main goal of the research.

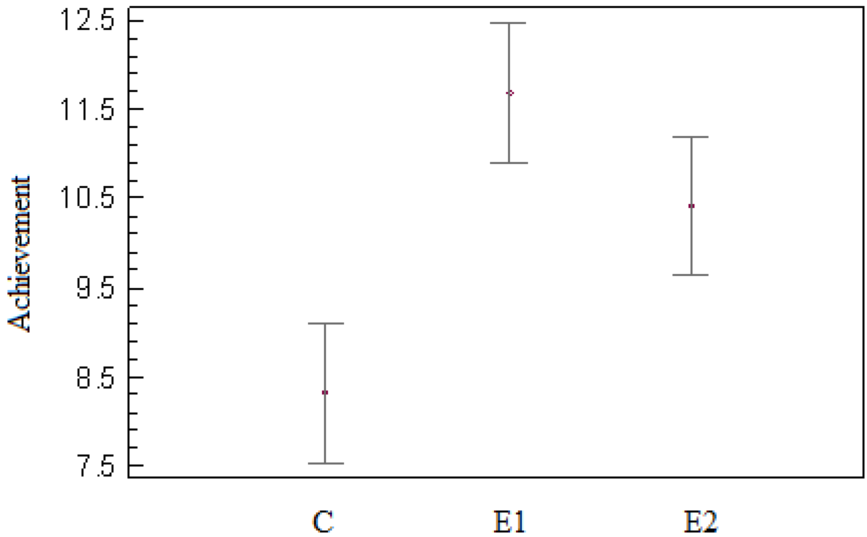
RESULTS AND DISCUSSION

Upon analyzing the results of the pretest and the posttest, there were analyzed changes in the students' achievements and cognitive load in three groups, and given explanations of the obtained differences. By analyzing the results of the initial test (pretest), and using ANOVA, it was determined that there were no statistically significant differences in the obtained number of points among E1, E2 and C groups ($F_{(2, 184)}$=0.42; p=0.6576). Balancing all three groups of students on the basis of their prior knowledge of physics enabled the further course of the research.

LIBEs and ICBSs Impacts on Student's Performance

One-way ANOVA was used to examine the potential effects of LIBEs and ICBSs on Student's Performance in teaching Surface Energy and Surface Tension, in comparison to the traditional instruction. The results of One-way ANOVA showed that there were statistically significant differences among the three groups in the achievement on the posttest ($F_{(2,184)}$= 9.05; p=0,0002<0,05). Figure 1 illustrates the distribution of students' scores on the posttest in three groups in a diagram.

Figure 1. Distribution of students' performance on posttest for E1, E2 and C groups



This diagram shows that the score of students of two experimental groups (E1 and E2) is shifted toward higher results, while it is shifted toward lower results in the group C. Students from E1 group achieved 11.7 points (58.5%) in average on the posttest, what was about the same result as students from E2 group (10.4 points, 52%), while the average success of students from C Group was 8.3 points (41.5%). Therefore, students from the experimental groups achieved higher scores than students from the control group. In order to determine between which groups there was a statistically significant difference in the achievement on the posttest, there was used a post hoc analysis, i.e. Tukey's test, which results were summarized in Table 1.

Table 1: Results of comparing the group pairs on the posttest of knowledge regarding the achievement (Tukey HSD)

(I) Group	(J) Group	Mean difference (I – J)	Sig.
E1	E2	1.3	.251
E1	C	3.4	.000*
E2	C	2.1	.025**

Legend. *p< ,001; **p< ,05

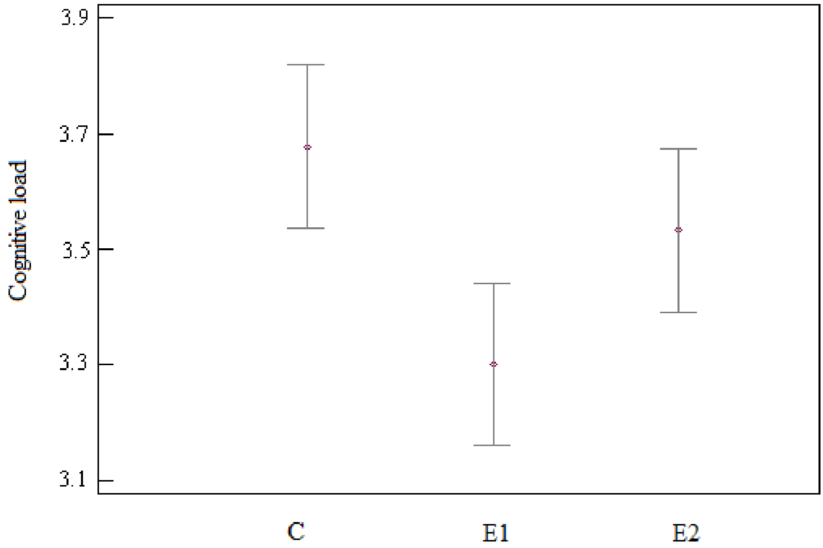
On the posttest, Tukey's test showed that there was a statistically significant difference in the students' achievement between the experimental groups (E1 and E2) and C group in favor of E1 and E2 groups. Comparing the average achievement of students E2 in relation to E1 group, the obtained difference was not statistically significant (1.3 points in favor of E2 group). Therefore, students who studied the topic Surface Energy and Surface Tension, made significantly better progress by applying LIBEs and ICBSs, compared to students who learnt the same content in the frontal form of instruction. Use of experiments for Physics teaching has been very favorable since Physics is an experimental science. Therefore, such method moves students closer to the way of scientific observation of physical phenomena. Multimedia is shown as favorable, since informatics revolution is involved into each aspect of life, and students are in a position to have greater amount of information. The use of innovations for Physics teaching is important when the final results are higher achievements of students.

LIBEs and ICBSs Impact on Student's Cognitive Load

In order to examine the efficiency of LIBEs and ICBSs compared to traditional teaching, according to the criterion of the cognitive load of students, the posttest assessed the invested cognitive load of students. If an educational strategy ensures high performance of students along with low values of cognitive load, it is considered to have a high instructional efficiency.

The results of One-way ANOVA showed that there were statistically significant differences between three groups in invested cognitive load on posttest ($F_{(2,184)}$=3.56; p= 0.0305<0.05). A diagram, which refers to the evaluation of invested cognitive load on posttest, is shown in Figure 2.

Figure 2: Distribution of students' assessments of invested cognitive load on posttest for E1, E2 and C groups



As it is seen in Figure 2, the mean value of self-perceived cognitive load of students from experimental groups (E1 and E2) is shifted toward lower values, while in group C, it is shifted toward higher results. Mean values are 3.30 for E1 group, 3.53 for E2 group and 3.68 for C group. These results are consistent with the results obtained for achievements. Namely, the students in E1 and E2 who accomplished higher average achievement than students in C group considered that less cognitive load was needed to be invested in order to solve the test tasks then students in C group. Unlike them, the students from C group, who had lower average achievements, considered that more cognitive load was needed for solving identical tasks. The obtained data indicated that use of innovation during teaching (LIBEs and ICBSs) was favourable regarding decreased cognitive load for students. In order to determine a significance of differences in the invested cognitive load in three groups, the results of Tukey's test are shown in Table 2.

Table 2: Results of comparing the group pairs on the posttest regarding the cognitive load (Tukey HSD)

(I) Group	(J) Group	Mean difference (I – J)	Sig.
E1	E2	-0.23	.239
E1	C	-0.38	.024*
E2	C	-0.15	.143

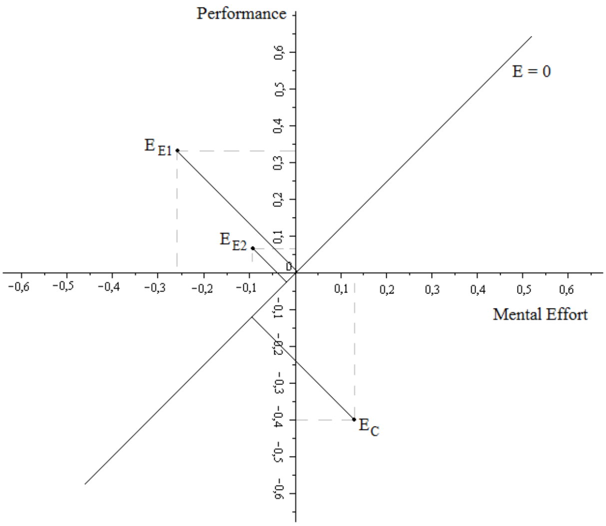
Legend. *p< ,05

The results of this test (Table 2) showed that the statistically significant differences in the invested cognitive load in solving the tasks on the posttest occurred only among students from E1 and C groups. Comparing the differences in the invested cognitive load between students from E1 and E2 groups, as well as from groups E2 and C, it could be concluded that they were not statistically significant. Application of ICBSs, and specially LIBEs, in learning Physical contents, enables students to master the terminology with less cognitive load, transform expressions, and apply them to everyday life situations. Students from E1 and E2 groups mastered the topic Surface Energy and Surface Tension on three cognitive domains with less invested cognitive load. In the domain of *Knowing of the facts*, E1 and E2 groups easier adopted the meaning of the term surface tension, and main features of the phenomenon, being enabled to distinguish adhesion and cohesion forces. In the domain of *Understanding the concepts*, with a bit of effort, the the experimental group of students could explain the reason why it was difficult to separate two parallel glass plates by vertical dispositioning if there was a small amount of water between them, etc. In the domain of *Application of knowledge*, it was possible to determine the coefficient of surface tension of water by using a thin metal ring hanged on an elastic spring, or to determine the fluid step height in the capillary that was open at both ends.

Comparative review of the instructional efficiency of LIBEs, ICBSs and a traditional teaching approach

To compare the efficiency of the applied teaching models, based on achievement (performances) of students and their invested cognitive load, there has been used the method suggested by Paas and Van Merrienboer (1993). Efficiency is calculated according to the formula $E = \frac{|R_z - P_z|}{\sqrt{2}}$, where R_z is a standardized value of self-perceived cognitive load and P_z is a standardized value of the students' performances. A sign of efficiency is defined according to the position of a point relating to the line E=0, which indicates zero efficiency. Values in the left quadrant indicate an increase in the instructional efficiency (higher performances and lower cognitive load), while values in the lower right quadrant indicate a decrease in efficiency (lower performance and higher cognitive load). Relative efficiency of a teaching strategy is calculated as a distance of the obtained point from the line E=0.

Figure 3: Graph of instructional efficiency for the LIBEs (E1), ICBSs(E2) and traditional teaching (C)



The obtained values for efficiency in LIBEs conditions (E_{E1}=0.42) and ICBSs conditions (E_{E2}=0.11), which dots are placed in the upper left quadrant, indicate a highly effective instructional strategies. Comparing the efficiency of these two experimental teaching strategies, LIBEs is more efficient for learning and understanding Physics. Unlike the experimental strategies, the E value obtained for C group (E_C=0.41), which dot is placed in the lower right quadrant, indicates that traditional teaching of Physics is less efficient than ICBSs, and especially from LIBEs.

The quantitative results of this study suggest that laboratory inquire-based experiments and interactive computer based simulations at the Physics classes contribute to significantly better understanding of the content Surface Energy and Surface Tension, what was confirmed by significantly higher score achieved in E1 and E2 groups of students in relation to the score achieved in C group. Application of LIBEs and ICBSs enables students to learn terms, transform expressions and apply them in a realistic life environment. In addition, on the basis of the results for evaluation of invested cognitive load, it has been concluded that the students from E1 and E2 groups assess that they invest less cognitive load when solving tasks in comparison to the students from C group. These findings, which are in line with the previous research (Kalyuga, 2008; Lee, Plass & Homer, 2006; Radulović & Stojanović, 2015; Renkl & Atkinson, 2003; Renkl, Gruber, Weber, Lerche & Schweizer, 2003) indicate that teaching instructions based on the use of laboratory inquire-based experiments and interactive computer based simulations equally contribute to an increase in students' performance, and the reduction of cognitive load unlike traditional teaching of Physics. The results obtained in this research prove that the instructive strategies are based primarily on the experiments, and then on simulations of the efficient teaching models when learning Physics.

CONCLUSION

The study examined the extent to which different teaching instructions focused on the application of laboratory inquire-based experiments and interactive computer based simulations improved understanding of physical contents in high school students, compared to traditional teaching approach. It also examined how the applied instructions influenced the students' assessment of invested cognitive load. Understanding the contents in Physics was measured by the students' scores obtained on the posttest of knowledge, while the students' invested cognitive load in solving the test was measured by the method of their self-assessment of the difficulty of the task on a five-point Likert scale. The method Paas & Van Merrienboer (1993) was used to compare the efficiency of applied teaching strategies, based on the students' achievement and their invested mental effort.

The findings revealed that the students who were taught with the application of LIBEs and ICBSs made statistically significant achievements in their test scores, in comparison to the students from C group. Differences in the achievement of students from LIBEs group and ICBSs group on the posttest of knowledge were not statistically significant, what indicates approximately equal importance of both teaching strategies in teaching Physics. The analysis of the mental effort self-assessment scale leads to the conclusion that the students of LIBEs group invested significantly less effort in resolving the posttest, in comparison to the students of ICBSs group and C group. Relative instructive efficiency for LIBEs and ICBSs, which is calculated on the basis of the results of the posttest and the cognitive load of students, has a positive value, which is higher than the obtained value for the efficiency of traditional teaching. Comparing the efficiency of two experimental methods, the teaching model based on the application of LIBEs is more efficient than the ICBSs application.

Finally, taking into account the abstraction of certain physical phenomena, the importance of the experiment and the research approach in teaching Physics is extraordinary. The fact that our students have lower achievements in Physics in relation not only to students from Hungary and Slovenia, but also in relation to the average scale, inevitably suggests that our students in Physics class should have much more activities to prepare and conduct hands-on experiments and work in small groups. This would enable development of critical thinking and improvement of their own cognition through cooperation, as well as exchange of knowledge with others.

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ЕФЕКТИ ПРИМЕНЕ ЛАБОРАТОРИЈСКИХ ИСТРАЖИВАЧКИХ ЕКСПЕРИМЕНАТА И КОМПЈУТЕРСКИХ СИМУЛАЦИЈА НА ПОСТИГНУЋА И КОГНИТИВНО ОПТЕРЕЋЕЊЕ УЧЕНИКА СРЕДЊЕ ШКОЛЕ У НАСТАВИ ФИЗИКЕ

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Апстракт

Основни циљ овог истраживања био је да се испита у којој мери ће различите наставне инструкције, фокусиране на примени лабораторијских истраживачких експеримената и компјутерских симулација, побољшати разумевање наставних садржаја из физике код ученика средње школе. Такође је циљ био и да се испита како примењене наставне инструкције утичу на когнитивно оптерећење ученика. Истраживање је спроведено на пригодном узорку од 187 ученика средње школе. Тест који је садржао задатке вишеструког избора коришћен је као инструмент за мерење образовних постигнућа ученика. У оквиру сваког задатка налазила се Ликертова петостепена скала за процену когнитивног оптерећења. Да би била утврђена значајност разлика у постигнућу и когнитивном напору ученика између група, као и за прорачун инструкционе ефикасности примењених наставних модела, поред дескриптивне статистике, примењене су једнофакторска анализа варијансе и Такијев тест контрастирања. Резултати су показали да инструкционе стратегије, које су засноване на коришћењу лабораторијских истраживачких експеримената и компјутерским симулацијама, подједнако доприносе бољем ученичком постигнућу уз истовремено смањење когнитивног оптерећења, у односу на традиционални приступ настави физике. Резултати инструкционе ефикасности добијени код ученика експерименталних група потврђују да примењене наставне стратегије представљају ефикасне наставне моделе.

Кључне речи: настава физике, компјутерске симулације, лабораторијски истраживачки експерименти, образовна постигнућа ученика, когнитивно оптерећење.

ЭФФЕКТЫ ПРИМЕНЕНИЯ ЛАБОРАТОРНЫХ ИССЛЕДОВАТЕЛЬСКИХ ЭСПЕРИМЕНТОВ И КОМПЬЮТЕРНЫХ СИММУЛЯЦИЙ НА ПОСТИЖЕНИЯ И КОГНИТИВНУЮ НАГРУЗКУ УЧАЩИХСЯ СРЕДНИХ ШКОЛ В ОБУЧЕНИИ ФИЗИКЕ

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Аннотация

Основная цель данного исследования – выявить, в какой степени разные учебные инструкции, направленные на применение лабораторных исследовательских экспериментов и компьютерных симмуляций, оптимизируют понимание учебных содержаний по физике у учащихся средних школ. Целью исследователей также было выявление воздействия примененных учебных инструкций на когнитивную нагрузку учащихся. Исследование было проведено на корпусе 187 учащихся средних школ. Тест, составленный из задач выбора одной из данной возможности, использовался в качестве инструмента для измерения образовательных постижений учащихся. В рамках каждой задачи применялась пятистепенная шкала Ликкерта для оценки когнитивной нагрузки. В целях выявления нагрузки была выявлена значимость отличий в постижениях и в когнитивном напряжении учащихся между группами, а в целях выявления инструкционной эффективности использованных учебных моделей, помимо дескриптивной статистики, было применены однофакторный анализ варианcы и тест сопоставления Такки. Результатя показали, что инструкционные стратегии, которые основываются на использовании лабораторных исследовательских эксперименов и компьютерных симмуляций, в одинаковой степени содействуют улучшению постижений учащихся с одновременным уменьшением когнитивной нагрузки, по сравнению с традиционным подходом преподаванию физики. Результаты инструкционной эффективности, полуьенные у учащихся из экспериментальных групп, подтверждают, что использованные стратегии обучения являются эффектыми учебными моделями.
Ключевые слова: обучение физике, компьютерные симмуляции, лабораторные исследовательские эксперименты, образовательные постижения учащихся, когнитивная нагрузка.